FOREST PLANTING POSSIBILITIES ON INDIANA COAL-STRIPPED LANDS

BY
GLENN H. DEITSCHMAN
RICHARD D. LANE

CENTRAL STATES
FOREST EXPERIMENT STATION
Columbus 15, Ohio
PHILIP A. BRIEGLEB, DIRECTOR

TECHNICAL PAPER NO. 131

DECEMBER 1952

ACKNOWLEDGEMENTS

Several members of the Central States Forest Experiment Station have provided invaluable assistance to the authors in preparing this manuscript. A. G. Chapman, Chief, Division of Forest Management Research, and L. S. Minckler, Forester, Carbondale Research Center, have contributed very helpful advice and suggestions. The authors are especially indebted to G. A. Limstrom, Forester, Division of Forest Management Research, under whose guidance much of the preliminary field work and data analyses were accomplished. The following members of the Station staff also took part in the field investigations:

John T. Auten	Deane W. Mather (Deceased)
Michael Kageorge	Robert W. Merz*
John E. Krajicek*	Nelson F. Rogers*

Charles J. Schissel

*Members of the present staff.

Grateful acknowledgement is also expressed for the helpful advice and criticism of Daniel DenUyl, Division of Forestry, Purdue University; H. Kohnke, Division of Agronomy, Purdue University; Charles E. Wier, Division of Geology, Indiana Department of Conservation; and Ralph F. Wilcox, State Forester, Indiana Department of Conservation. Special thanks are due L. E. Sawyer and S. D. Fox of the Indiana Coal Producers Association for their consistent cooperation and support in all phases of this work, and to the member companies of the Association for their cooperation in supplying land, planting stock, labor, and other material help in conducting the investigations and research reported here.

ERRATA

(For Technical Paper No. 131)

Table 10, Page 19.

The grand total for the second column should be changed from "23.6" to "23.4."

Figure 12.

The regression-line label, "Austrian Red Pine," should be changed to "Austrian Pine."

Page 35.

Line 6 under "Cultural Treatments"; change "(fig. 11)" to "(fig. 12)."

Page 36.

Line 8 from top of page; change "(fig. 23)" to "(fig. 22)."

Page 49.

In the "Literature Cited," the "Unpublished manuscript," Citation No. 15, was published in 1952 as Technical Paper No. 130, and entitled "Effects of grading strip-mined lands on the early survival and growth of planted trees."

Page 52.

The scientific name for shortleaf pine should be changed from "*Pinus echniata* Mill." to "*Pinus echinata* Mill."

CONTENTS

Page

Introduction - 1
Review of Literature - 3
Coal Geology- 4
The Composition of Stripped-Land Materials- - - - - - - 4
Use of Coal-Stripped Lands- - - - - - - - - - - - - - - 5
Extent and Character of Coal-Stripped Lands- - - - - - - - - - 7
Effects of Glaciation upon Surface Materials- - - - - - 7
Origin of Highly Acid Materials - - - - - - - - - - - - 8
Influence of Mining Methods upon Acidity- - - - - - - - 9
Coal Seam Overburdens - - - - - - - - - - - - - - - - - - 10
Block Coals- 11
Minshall Coal- 12
Coal III - 13
Coal IV- 14
Coal V - 15
Coal VI- 16
Coal VII - 17
Factors Influencing Strip-Land Quality- - - - - - - - - 18
Natural Forests on Coal-Stripped Lands - - - - - - - - - - - - 18
Older Forest Plantings on Coal-Stripped Lands- - - - - - - - - 20
Selection of Sample Plantations - - - - - - - - - - - - 20
Method of Sampling- 21
General Description of Plantations- - - - - - - - - - - 21
Plantation Growth and Development - - - - - - - - - - - 23
Pine Plantations - - - - - - - - - - - - - - - - - - 23
Mixed Pine and Hardwood Plantations- - - - - - - - - 27
Hardwood Plantations - - - - - - - - - - - - - - - - 29
Major Environmental Factors Affecting Later Plantation Success - - - - - - - - - - - - - - - - - - 32
Acidity- 32
Topography and Texture - - - - - - - - - - - - - - - 33
Erosion- 34
Plantation Management Aspects - - - - - - - - - - - - - - 34
Protection - 34
Cultural Treatments- - - - - - - - - - - - - - - - - - 35
Regeneration - 35
Forest Planting Experiments- - - - - - - - - - - - - - - - - - - 36
Species Adaptation- 36
1945 Experiment- 36
1947 Experiment- 38
1949 Experiment- 40
Black Locust as a Nurse Crop- - - - - - - - - - - - - - - 40
Locust-Hardwood Mixtures - - - - - - - - - - - - - - - 41
Underplanting with Other Hardwoods - - - - - - - - - 41

Page

Summary - 43
Results of Indiana Studies - - - - - - - - - - - - - - - - - 43
Forest Planting Recommendations - - - - - - - - - - - - - - 44
Planting Guides - 45
Supplementary Recommendations - - - - - - - - - - - - 46
Literature Cited - 48
Appendix - 52

Frontispiece--Many families enjoy picnics and fishing at several of the lakes on the Greene-Sullivan State Forest, formerly a strip-coal mine.

FOREST PLANTING POSSIBILITIES ON INDIANA COAL-STRIPPED LANDS

by

Glenn H. Deitschman and Richard D. Lane[1/]

INTRODUCTION

Open-cut mining of coal is not a new industry in Indiana. Early settlers in the southwestern part of the state found exposed seams of coal along creek beds, cliffs, and eroded slopes. Shortly after the Civil War, stripping of the exposed seams was started on a commercial scale. These first operations removed the loose soils and shales with teams and slip-scrapers having about one-quarter yard capacities. Stripping was strictly a seasonal affair and the coal was mined for local home use. By 1911 coal-stripping had begun to make an important contribution to coal production in Indiana. In 1950, 54 percent of the coal produced in the state was mined by the open-cut method.

The dramatic changes in landscape caused by strip mining often are viewed with alarm because the area of rich agricultural lands stripped is frequently exaggerated, the limits of strippable coal reserves sometimes are overestimated, and the stripping creates new land-use problems. The area of coal-stripped lands in the state on July 1, 1951, was estimated to be 50,988 acres. This is less than 0.2 percent of the land in the state and 1.2 percent of the 15 counties where coal stripping was found. Pike County, with the greatest concentration of stripping in the state, had 5 percent of its lands mined. Clay County was next with less than 4 percent, and Dubois County had the least with only 12 acres of stripped lands in 1949. The average value of products sold, traded, or used per farm in Indiana in 1940 was slightly over $1400. In 13 of the 15 counties having stripping, the value of farm products was below the state average and ranged down to a low of $548 per farm (4).[2/] The coal-bearing formations of Indiana are confined to the west central and southwestern parts of the state (fig. 1). The depth and quality of known coal seams will restrict strip mining to only a small part of this area.

1/ Research forester and Forester in Charge, respectively, of the Carbondale Forest Research Center, Central States Forest Experiment Station.

2/ Numbers in parenthesis refer to literature cited.

Over 60 percent of the coal-stripped lands of Indiana has a good to fair density of natural or introduced forest cover according to a study completed in 1947 (14). An additional 2 percent of these lands had been converted to pasture and another 9 percent were well covered with grasses, legumes, and weeds. The remaining mine banks were classified as barren. They were made up of recent strippings and of lands too acid for immediate use. The field examination indicated that probably 95 percent of all coal-stripped lands in the state could be converted to productive uses.

Two stripped areas totaling 4,035 acres have been turned over to the Indiana Department of Conservation for public use. These are known as the Scales Lake and the Greene-Sullivan State Forests. Both forests contain many lakes that are used by the public for picnicking, swimming, fishing, and other forms of recreation (frontispiece). Another 600-acre strip-mined tract has been deeded to the city of Linton for development of the Lee-Sherrard Park. There are over 20 lakes in this tract, and other recreational facilities, such as bridle paths and trap-shooting ranges, are being prepared. Several other small strippings are being used by Legion posts or conservation clubs, or for home sites. Many of the mining companies are developing recreational facilities on their mined lands for employees and guests (fig. 2).

One of the earliest ways of using stripped lands in Indiana was tree growing. Complete records are not available, but a few operators, with the advice and cooperation of the Indiana Department of Conservation, began planting as early as 1926. By 1930 nine of the larger companies were committed to a voluntary tree-planting program on their strip-mined lands. The Indiana Coal Producers Association, an organization of strip-mine operators, was founded in 1918. It employs a forester to help the member companies develop orderly planting programs, protect and manage their forests, and cooperate with groups studying ways of using stripped lands. The groups include the Indiana Department of Conservation, Purdue University, and the Central States Forest Experiment Station.

In 1941 the Indiana Legislature passed a law requiring all operators to revegetate 101 percent of areas mined each year. This law was amended in 1951 to require owners to: (1) revegetate areas where mining changed the contours; (2) grade prospective pasture areas and unsightly ridges and peaks; (3) construct earthen dams in final cuts where lakes will be formed; and (4) establish access roads or lanes through forest plantings. These laws are administered by the Division of Forestry, Indiana Department of Conservation. As a result of voluntary planting programs and legislation, nearly 29,000 acres of forest plantings have been established on Indiana coal-stripped lands. Some of the earlier plantings now contain merchantable timber.

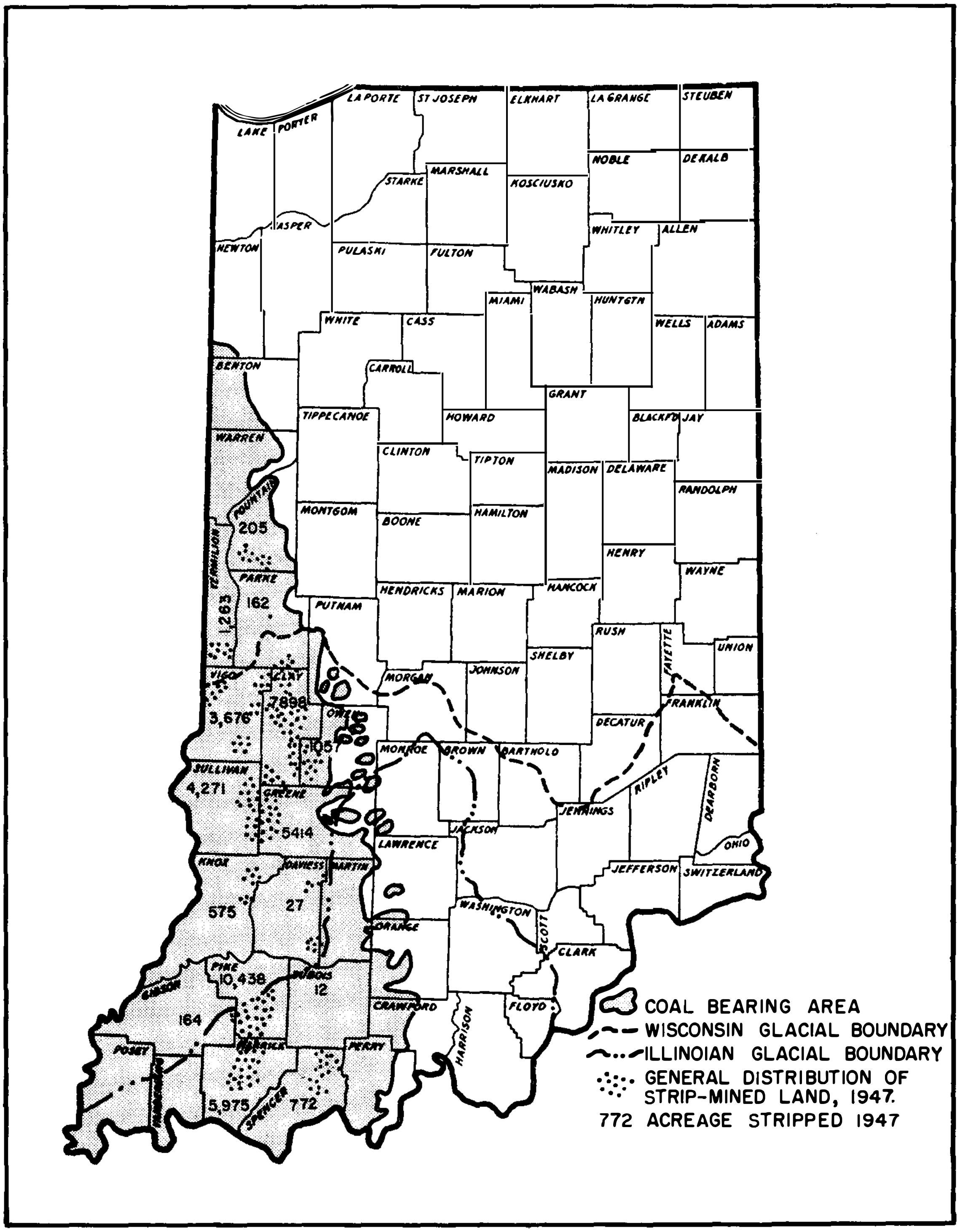


Figure 1.--The coal-bearing area, glacial boundaries, and distribution of strip-mined land in Indiana, 1947.

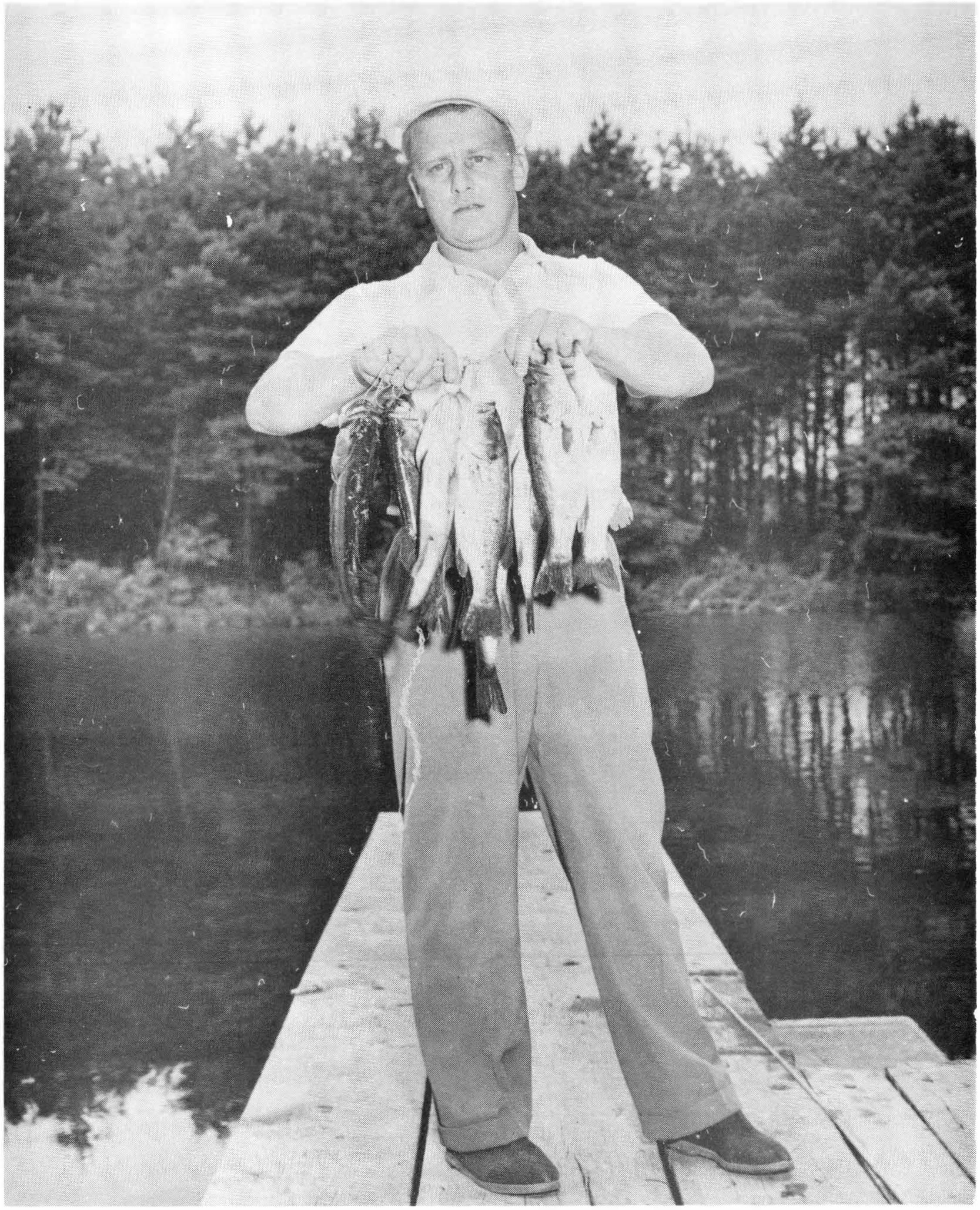


Figure 2.--Fishing is good in many of the strip-mined lakes. Bass and blue gills are abundant in this 20-year-old company-developed lake in Greene County.

Despite the lack of long experience and well-founded scientific bases, real progress has been made in reclaiming coal-stripped lands in Indiana. Mine banks have few of the characteristics common to soils; they are essentially a conglomerate of the materials removed in stripping and they represent a new medium for growing plants. Unquestionably, mistakes and failures were common in the early attempts at strip-mine reclamation, but the experience gained from these mistakes coupled with continuing research should result in more efficient and economic use of Indiana's coal-stripped lands.

This publication was prepared to (a) list and describe major conditions on Indiana coal-stripped lands that affect forest plantings, and (b) present tentative forest planting guides and recommendations for the more important bank types and conditions within the state. These descriptions and recommendations are based upon a reconnaissance of strip-mined lands, an examination of older company plantings and natural forests, and the results of a number of forest planting experiments. Since the company and experimental plantings have not reached maturity, the recommendations cannot be final and conclusive. They are presented here to help reduce future planting failures and to assist those who are planning forestation programs to evaluate site factors on stripped lands.

The recommendations in this paper are restricted to forest plantings but it is not intended to imply that Indiana coal-stripped lands should be used exclusively for forestry. Undoubtedly, many of these lands can be used advantageously for pastures, orchards, recreational areas, or wildlife refuges. The descriptions presented here should be of value to investigators dealing with these other uses of coal-stripped lands in the state.

REVIEW OF LITERATURE

Investigations have been made of the geology of coal deposits, the character and composition of overburden materials, and methods of rehabilitation. These have provided considerable information on the characteristics and potential productivity of strip-mined land. The following review of literature is limited to brief mention of a few published reports which illustrate the nature and scope of the problems involved in utilizing stripped areas in Indiana.

COAL GEOLOGY

Stripped lands are heterogeneous mixtures of materials which overlaid the coal strata. A knowledge of the composition and variations of typical geologic formations above coal seams is helpful in understanding the development of different types of banks. Much of this information is available from extensive geologic surveys of coal resources.

Early exploratory studies of the Indiana coal fields were reported in 1862 by Lesquereux (13). Near the turn of the century, Ashley (2) gave comprehensive descriptions of the coal geology of the state and contributed the system of nomenclature still in use. He also observed the variability in depth and kind of overlying strata which often is found within relatively short distances. Some of the more constant formations associated with the major coal seams have been described by Logan (18) and by Weller and Wanless (33). These identifying strata were used, in part, by Weller and Wanless to correlate the minable coals of Illinois, Indiana, and western Kentucky. Wier (34) has given an excellent summary of the geology of coal deposits in the Jasonville Quadrangle which occupies portions of Clay, Greene, and Sullivan Counties.

THE COMPOSITION OF STRIPPED-LAND MATERIALS

Limstrom (14) found acidity and texture of mine-bank surfaces to be the major factors determining the potentialities of strip-mined land for tree growth. Using these characteristics, he developed the following classification system for mine banks:

Acidity Classes

1. Toxic. More than 75 percent of area with pH less than 4.0.[3/]

2. Marginal. Fifty to 75 percent of area with pH less than 4.0.

3. Acid. More than 50 percent of area with pH of 4.0-6.9.

4. Calcareous. More than 50 percent of area with pH of 7.0 or higher.

5. Mixed. Approximately equal portions of toxic, acid, and calcareous areas.

3/ The degree of acidity is expressed by pH numbers. A pH of less than 4.0 is considered to be lethal to most plants; pH 4.0-6.9 is acid but not toxic to many species; pH 7.0 is neutral; and pH above 7.0 is alkaline, or "calcareous."

Textual Classes

A. Predominantly sands.
B. Predominantly loams and silty shales.
C. Predominantly clays.

By combining an acidity class and a textural class, an area can be designated as having a definite bank type, such as toxic loam (1B), acid sand (3A), or mixed clay (5C).

Laboratory analyses of representative strip-land materials in Indiana were made by Stiver (31). He found that the average bank contained about 40 percent soil-sized particles (2 mm. or less in diameter). This portion was itself composed of nearly equal amounts of sand, silt, and clay. Determination of nutrient mineral content showed no deficiencies of potassium, calcium, magnesium, or boron. The nitrogen and phosphorus contents were low, but phosphorus generally was present in amounts greater than in adjacent unstripped land.

Grading of strip-mined lands generally has been detrimental from the standpoint of later forestation. The grading machinery compacts the surface material causing slow internal drainage and poor aeration. Merz and Finn (22) have reported the average rate of water infiltration on ungraded banks in Ohio to be more than 10 times greater than that on nearby graded banks. Comprehensive investigations of grading effects on moisture conditions and early plantation success were conducted by Limstrom (15). Significant differences in favor of the ungraded banks for forest growth were reported for most types of bank material.

USE OF COAL-STRIPPED LANDS

The possibilities of establishing successful forest plantings on strip-mined lands have been the subject of considerable research. Many of the results obtained by workers in other states can be applied to Indiana. General information from a region-wide survey of stripped lands and tentative forest planting recommendations have been reported by Limstrom (14). Later, Limstrom and Merz (17) made a more detailed analysis of the effects of important bank characteristics on the early growth and development of planted trees in Ohio. Similar investigations in Illinois were reported by Limstrom and Deitschman (16), in Kentucky by Merz (21), and in the Western Interior Coal Province by Rogers (26).

The value of black locust as a nurse crop for associated hardwoods in strip-land plantings was first investigated by Chapman (5). He concluded that, "If planted to the proper density, locust will afford protection against drying winds and high fluctuations

of temperature near the ground surface, deposit sufficient litter to reduce evaporation to a minimum at the 'soil' surface, add organic matter to the spoils, aid in stabilizing the bank surface, and develop a network of nodule-forming roots to supply the much-needed nitrogen. Accomplishment of these things will improve site conditions sufficiently so that native hardwoods can be established by planting, or naturally, if seed sources are present." In a later study Deitschman (7) found the early growth of such species as black walnut and yellow-poplar to be greatly accelerated when planted under locust cover. However, Limstrom and Merz (17) caution against delaying the underplanting too long because a dense weed and briar undergrowth will develop and choke out all but the most tolerant tree seedlings.

In a bulletin concerned with the reforestation of idle lands in Indiana, DenUyl (9) has discussed the suitability of various species for planting and the principles of plantation growth and management. Much of this information can be applied to strip-mined lands in the state. Arnott (1) reported the establishment and first-year survival of experimental hardwood plantings on a wide range of strip-land sites. Of 10 species tested, he noted that black locust, green ash, silver maple, and sycamore had the best initial survival.

A valuable contribution to the knowledge of forest growth on Indiana stripped lands was made through the early plantings of several mine operators in the state. Some of the background of these plantings and subsequent observations have been reported by Wilcox (35) and by Sawyer (28). Sawyer states that planters "... selected some species which were doomed to failure, but the early failures are now keeping us from repeating these errors in our present and vastly more far-reaching planting program. Other species used in those early plantings which not only survived but which have thrived are still our guide in the selection of species for present use."

Among other possible ways of using Indiana mine banks, Stiver (31) considers wildlife and recreational development promising. He limits the agronomic uses of the banks to pasture on areas which are generally calcareous and do not contain numerous large rock fragments and concludes that "Tillage practices are not foreseen upon spoil material, even if levelled, within any reasonable length of time."

EXTENT AND CHARACTER OF COAL-STRIPPED LANDS

A reconnaissance of Indiana coal-stripped lands was made by the Central States Forest Experiment Station in 1947. The total strip-mined area at that time, 41,909 acres, was distributed among 15 counties (fig. 1). Acid loams and silty shales occurred on nearly three-fourths of the stripped lands in the state.[4/] About a fifth of the total area was classified as calcareous and less than 2 percent was found to be too acid for tree planting.

EFFECTS OF GLACIATION UPON SURFACE MATERIALS

Glacial till is usually calcareous, contains much soil-size material, and often has an important effect upon the texture and acidity of coal-stripped lands. Two ice sheets have covered parts of the coal-producing area of Indiana (fig. 1). The earlier Illinoian glaciation progressed farther south, covering all of the state except a relatively small triangular section in the south-central part. Later, approximately the northern two-thirds of the state was covered by the Wisconsin glaciation which deposited additional till above the Illinoian drift in this area. On the basis of these glacial boundaries the area of coal deposits in the state can be sub-divided into the Illinoian glaciated, the Wisconsin glaciated,[5/] and the unglaciated regions.

The two glaciated regions show differences in composition of glacial deposits, as well as in their average depth. The Illinoian till is finer textured and more acid because of its longer exposure to weathering. Thornbury (32) reports that calcium carbonate has been removed to a depth about three times that of the younger Wisconsin till. To determine the effect of these factors on bank quality, data from the 1947 reconnaissance of strip-mined land were analyzed to compare the proportions of major acidity classes occurring in each region. More than three-fourths of the stripped land in the Wisconsin glaciated region was found to be predominantly calcareous as compared to less than one-fourth in the region of Illinoian glaciation (table 1). In the unglaciated region of the state only 9 percent of the mine banks were classified as calcareous. Considerable local variation within each of the three regions can be expected because of: (1) uneven glacial

---

4/ Tables summarizing the reconnaissance data by counties, bank types, plant covers, and coal seams have been published (13). They are reproduced, with minor revisions, in the Appendix.

5/ Although this region was also covered by the Illinoian glaciers, the region is so named in this paper to distinguish it from the region covered solely by the Illinoian glaciers.

deposition; (2) effects of post-glacial erosion and sedimentation; (3) differences in depth and occurrence of the strata overlying coal seams; and (4) differences in mining methods.

Table 1.--Percentage of Indiana strip-mined lands in each acidity class by regions of glaciation, 1947

Regions	Acidity of bank material				
	Toxic	Marginal	Acid	Calcareous	Mixed
	Percent in each region				
Wisconsin glaciated	3	0	15	78	4
Illinoian glaciated	1	1	73	23	2
Unglaciated	3	7	81	9	0

ORIGIN OF HIGHLY ACID MATERIALS

Less than 2 percent of the stripped areas in Indiana were found to be entirely unplantable because of extreme acidity, but a much larger percentage of the spoils were only slightly less acid. The kinds of trees that can be planted on such areas are limited to acid-tolerant species and even they may suffer reduced growth rates.

High acidities on strip-mined land are primarily caused by the exposure and subsequent oxidation to sulphuric acid of such sulphur-bearing compounds as pyrite, marcasite, and complex poly-sulphides. Because this oxidizing process is slow, some coal-stripped lands become increasingly acid for several years after mining is completed. Therefore, acidity tests on fresh spoils may give unreliable information as to the future suitability of the area for plant growth. If the acid-forming materials are recognized, costly planting failures can be reduced. Sulphur compounds commonly are concentrated in strata near the coal formations and it may be possible to predict future acid-toxicity by a visual estimate of the proportion of these materials on the mine-bank surfaces. In doubtful cases, it may be advisable either to postpone the preplanting examinations for 1 or 2 years after mining, or to test samples of the bank material for sulphur content. A quantitative field method for determining sulphur has been developed. Briefly, the procedure is as follows:

Pulverize 2 - 3 grams of material to be tested and place in a small test tube. Add about 1 gram of granular zinc (20-30 mesh) and mix by shaking the tube.

Add about 2 - 3 ml. (an eyedropper-full) of 6 N. hydrochloric acid. Wait until fumes from the reaction fill the tube, then place a sheet of filter paper, freshly impregnated with 0.6 N. lead acetate solution, directly over the mouth of the test tube. Hold for 5 seconds and remove. The degree of discoloration of the filter paper indicates the relative concentration of sulphur in the sample:

Color	Sulphur content
Dark brown with silvery cast	High
Brown	Moderate
Light tan	Low

Laboratory analyses made by Southern Illinois University (25) have shown a general correlation between the results of this field test and the actual total quantity of sulphur present.

INFLUENCE OF MINING METHODS UPON ACIDITY

The concentration and distribution of sulphur in overlying strata vary somewhat by coal seam, but these differences are not readily apparent in the over-all proportion of acidic and calcareous banks produced with each seam (table 2). One of the factors obscuring the relationship between amounts of sulphur in the overburden and bank acidity is variation in methods of strip mining.

Table 2.--Area of strip-mined land by coal seam and acidity class, 1947

Coal seam	Acidity classes					Total
	Toxic	Marginal	Acid	Calcareous	Mixed	
	Acres					
Block	26	0	5,804	1,414	589	7,833
Minshall	46	0	76	94	0	216
Coal III	22	27	2,066	266	0	2,381
Coal IV	68	0	1,986	1,356	0	3,411
Coal V	439	1,141	16,023	3,513	68	21,184
Coal VI	0	0	4,407	1,262	64	5,733
Coal VII	98	26	968	59	0	1,151
Total	699	1,194	31,330	7,965	721	41,909

In the usual stripping operations, each swing of the shovel or dragline bucket removes portions of each rock and earth stratum above the coal. The resulting bank surface contains about the same proportions of the various materials as were in the highwall. However, in some instances where the upper material is easily dislodged, most of it is removed first and the underlying rock formations are removed later. As a result, the final bank surface may contain a high proportion of sulphurous rock in spite of its limited occurrence in the overburden. A similar result is occasionally produced by "cleaning" highly pyritic materials from the coal surface with the stripping equipment and casting these on top of the banks.

Several strip-mining techniques have been used to get the upper-earth portion of the overburden on the bank surface. One method uses a dragline and power shovel working in tandem. The dragline follows the shovel, removing the upper soil and earth layers from the next cut and casting them over the predominantly rock material stripped by the shovel. Similar results have been obtained by a single-unit operation employing a dragline which strips from a bench.

By first identifying acid-forming strata in the overburden by means of the previously described test for sulphur the operator may be able to bury these materials with only slight modification of usual stripping methods.

COAL SEAM OVERBURDENS

Only 8 of the more than 20 coal seams found in southwestern Indiana have been strip mined to any great extent. These seams outcrop generally from east to west in ascending order of depth and age, as follows: Lower Block, Upper Block, Minshall, Coals III, IV, V, VI, and VII. Where the Upper Block coal is thick enough for stripping, it is commonly mined in conjunction with the Lower Block. These two seams are combined here under the single name of "Block Coals."

Detailed examinations were made of 33 highwalls located throughout the strip-mining area of the state. These highwalls were examined to determine for each coal seam the major characteristics of associated strata which would affect the properties of resulting stripped land. Overburden materials were described as to kind of material, thickness, acidity, and sulphur content as determined by the field method. For a given coal seam, the type and characteristics of overlying rock formations were fairly consistent where glaciation or erosion had not disturbed their natural occurrence. No attempt was made to compute the average depth of

soil or dissociated earth material in the upper part of the overburden because of its extreme variability. These upper layers consisted chiefly of soil-sized material and varied more in depth and character with the topography and glacial history than with the different coal seams. The following descriptions of typical overburden composition are based upon the highwall analyses and upon the published reports of various coal geologists.

Block Coals

The highwall examinations disclosed only three major rock strata above the Block Coals (table 3). These were slightly acid to calcareous and low in sulphur. Black, slaty shale usually overlies the coal but occasionally is replaced by a bed of laminated sandy shale. The sandy shale material commonly occurs over various other coal seams also, and is described by Ashley (2) as a peculiar combination of thin alternating layers of sandstone and shale.

Table 3.--Characteristics of average strata above Block Coals 1/

Strata (Top to bottom)	Thickness	Acidity	Sulphur content
	Feet	pH	
Soil and dissociated earth materials	-	-	None
Tan sandstone, fine-grained, massive	4	6.0	None-low
Gray sandy shale, thin-bedded	13	7.0	Low
or			
Black shale, fissile	9	5.5	Moderate

1/ Based upon examination of six highwalls.

Minshall Coal

Because strip mining for Minshall Coal is limited, only one fully exposed highwall, located in southern Fountain County, was found (table 4). In this instance nearly two-thirds of the total overburden consisted of calcareous glacial till. The underlying limestone and shale also were calcareous but contained large quantities of sulphur compounds. In Parke County, Logan (18) mentions that more shale occurs above the limestone and in places the limestone rests directly upon the coal.

Table 4.--Characteristics of average strata above Minshall Coal[1/]

Strata (Top to bottom)	Thickness	Acidity	Sulphur content
	Feet	pH	
Soil and glacial drift	-	-	None
Gray limestone, fossiliferous, massive	5	7.0+	High
Black shale, fissile	10	7.0	High

1/ Based upon examination of one highwall.

Coal III

Coal III, also called the "Staunton" or "Seelyville" coal, was usually overlain by calcareous to moderately acid strata. Relatively high concentrations of sulphur were noted in most of this material, especially near the rider vein, Coal IIIa (table 5). The type of rock forming the roof of Coal III varied considerably from place to place. Most commonly it was a laminated gray sandy shale with interbedded black shale which increased with depth. However, in some localities this was replaced by a dark gray, thick-bedded or thin-bedded shale which occasionally was fossiliferous. In the Jasonville Quadrangle, Wier (34) reports that the roof may also be a brown, micaceous sandstone.

Table 5.--Characteristics of average strata above Coal III[1]

Strata (Top to bottom)	Thickness	Acidity	Sulphur content
	Feet	pH	
Soil and dissociated earth material	-	-	None
Light gray shale, thick-bedded	6	6.0	Low
Black shale, fissile	5	7.0	High
Coal IIIa	1	5.0	High
Gray fire clay, or thick-bedded gray shale	2	7.0+	High
Gray sandy shale, thin-bedded	7	6.0	Moderate-high

1/ Based upon examination of five highwalls.

Coal IV

The lower overburden strata of Coal IV ("Linton Block") generally were moderate in both acidity and sulphur content except near the rider vein, Coal IVa (table 6). The roof of Coal IV was a black or dark gray thin-bedded shale in all highwalls examined (fig. 3). However, Logan (18) and Wier (34) both mention that it sometimes is a layer of sandstone.

Table 6.--Characteristics of average strata above Coal IV[1]

Strata (Top to bottom)	Thickness	Acidity	Sulphur content
	Feet	pH	
Soil and dissociated earth material	-	-	None
Black shale, fissile	3	6.0	High
Coal IVa	1	4.0-	High
Gray fire clay, often ferruginous	2	4.5	Low
Gray shale, thick- to thin-bedded	4	7.0	Moderate
Gray sandstone, fine-grained, massive (may be absent)	12	6.5	Moderate
Black shale, thin-bedded	10	6.5	Moderate

1/ Based upon examination of four highwalls.

Coal V

Most of the rock strata over Coal V (known also as the "Petersburg" or "Alum Cave" coal) were low in acidity but were found to be highly sulphurous (table 7). In Greene County and areas farther north, the rider vein, Coal Va, appeared to be absent and the distribution of sulphur was limited to the lowermost strata. The roof of Coal V ordinarily consisted of black shale. Wier (34) describes the lower half of this shale as being soft and readily weathered, while the upper half is fissile. Above the shale lay a persistent bed of hard, impure limestone, succeeded either by gray silty sandstone or gray and black laminated sandy shale (fig. 4). Under Coal Va, black slaty shale was occasionally replaced by black clay which had a very high sulphur content.

Table 7.--Characteristics of average strata above Coal V[1/]

Strata (Top to bottom)	Thickness	Acidity	Sulphur content
	Feet	pH	
Soil and dissociated earth material	-	-	None
Gray or brown sandstone, coarse-grained, massive	6	6.0	Low
Gray sandy shale, thin-bedded	3	5.5	Low
Coal Va	1	4.0-	High
Black shale, fissile	3	6.0	High
Gray sandstone, fine-grained, massive, or gray sandy shale, thin-bedded	10	6.0	High
Dark gray limestone, massive	3	7.0+	Moderate
Black shale, fissile	4	7.0+	High

1/ Based upon examination of eight highwalls.

Coal VI

The rock overlying Coal VI was found to consist largely of calcareous or slightly acid shale (fig. 5) with a high sulphur content (table 8). A light gray, massive sandstone, up to 12 feet in thickness, occasionally entered between the two beds of shale. This, also, was calcareous and tested high in sulphur.

Table 8.--Characteristics of average strata above Coal VI 1/

Strata (Top to bottom)	Thickness	Acidity	Sulphur content
	Feet	pH	
Soil and dissociated earth material	-	-	None
Gray limestone, fragmentary, discontinuous	0 - 2	7.0+	Low
Light gray shale, thick-bedded	12	7.0+	High
Dark gray shale, thick- to thin-bedded	14	7.0+	High

1/ Based upon examination of six highwalls.

Figure 3.--The overburden of Coal IV usually contains a high proportion of shale and clay. Coal IVa is visible as an intermittent black streak in the upper left corner of this highwall in Pike County.

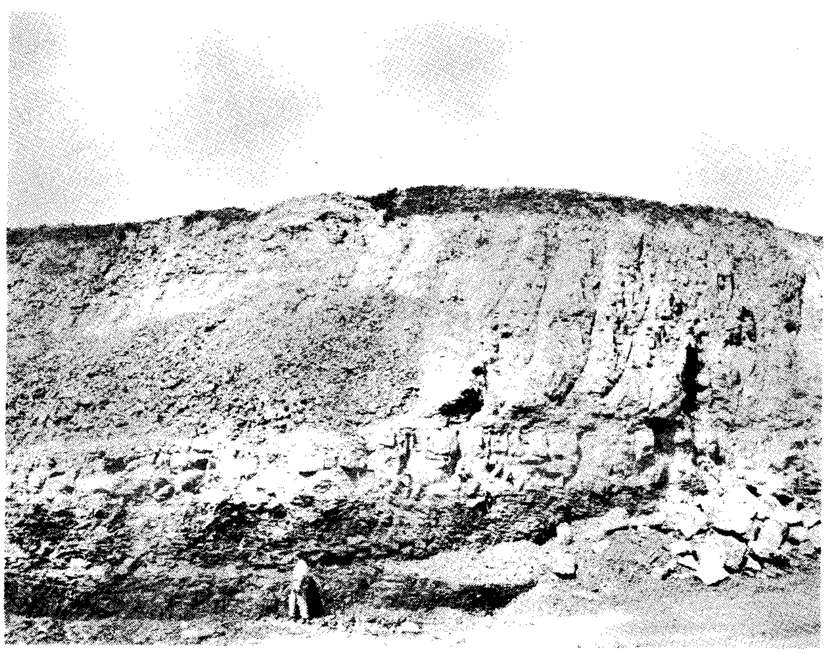


Figure 4.--Massive sandstone and limestone are prominent in the overburden of Coal V. In this Vigo County operation, nearly half of the overburden consisted of calcareous glacial till and boulder clay.

Coal VII

The shale and sandstone overlying Coal VII (fig. 6) tended to be slightly acid with a high sulphur concentration toward the bottom of the overburden (table 9). The lower portion frequently consisted of gray laminated sandy shale which graded downward into dark gray shale. In one instance an extremely acid bed of sulphurous gray clay, about a foot thick, directly overlaid the coal.

Table 9.--Characteristics of average strata above Coal VII[1/]

Strata (Top to bottom)	Thickness	Acidity	Sulphur content
	Feet	pH	
Soil and dissociated earth material	-	-	None
Yellowish-brown sandstone, coarse-grained, massive	4	6.0	None
Light gray sandstone, fine-grained, massive	10	7.0	High
Gray shale, thick-bedded	15	6.0	High

1/ Based upon examination of three highwalls.

FACTORS INFLUENCING STRIP-LAND QUALITY

In the reconnaissance, glaciation was found to have the most consistent effect upon surface materials and can be used as the basis for dividing Indiana stripped lands into three broad regions (fig. 1). The quality of mine banks for plant growth was observed to be often directly related to depth and age of glacial till before stripping. Throughout the strip-mining area of the state, the rock types above a given coal seam were found to be fairly consistent. Rock composition, depth of glacial till, and stripping method largely determine texture and acidity which are the dominant characteristics governing the growth of plants. They may, then, be used to further classify strip-mine lands in the state for forest planting.

With a given stripping method and proper identification of overburden composition, it may be possible to predict the plantability of strip-mine lands. Failure to recognize the factors influencing texture and acidity and their effect upon plantation success has caused the loss of at least one-tenth of the early plantations on Indiana stripped lands.

NATURAL FORESTS ON COAL-STRIPPED LANDS

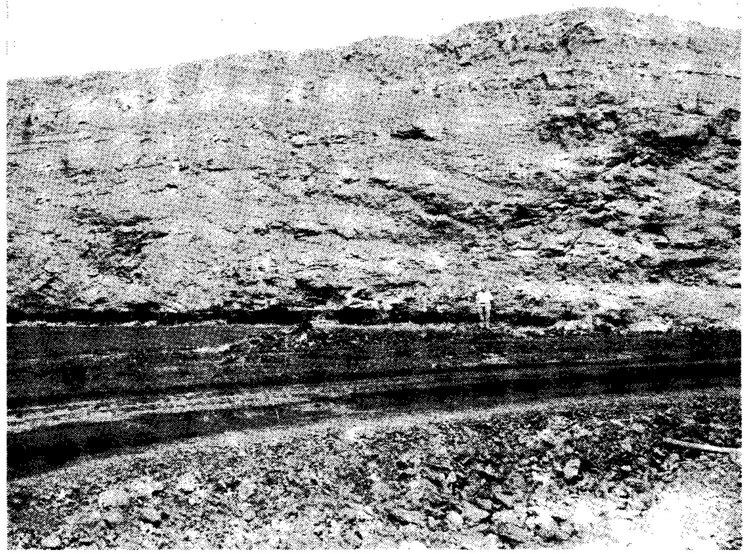
Nearly 10 percent of the coal-stripped lands in the nine Central States supported natural forest cover in 1947 (14). In Indiana about 16 percent of the mined area was in natural forests. One of these forests, located on stripped lands in Sullivan County, was studied during September 1951.

The larger trees found in the stand were 28 years old, indicating that stripping occurred before or during the early 1920's. Probably Coal VII was removed in the mining operation. The bank surfaces were mostly friable silt loam with a pH of 5.5 to 6.5. When examined, the stand contained 4,631 trees per acre ranging from reproduction less than 5 feet tall to saw-timber trees 18 inches in diameter at breast height[6] (table 10). The total per-acre basal area was 23.6 square feet for poles and saw timber. These same trees contained 291.2 cubic feet per acre and the saw-timber trees alone contained 1,126 board feet per acre.

These data indicate that a heavy volunteer stand of timber may develop on stripped land, but they are somewhat misleading. The open-grown saw-timber trees were short-boled, limby, and contained few high-grade products (fig. 7). Over 67 percent of the saw-timber trees contained one 16-foot log or less. Except

6/ The diameter at 4-1/2 feet above the ground, hereafter abbreviated as d.b.h.

Figure 5.--Thick-bedded, dark gray shale occupies the lower one-third of this Coal VI overburden in Vermillion County. Materials above the shale consist of two distinct ages of glacial deposits.



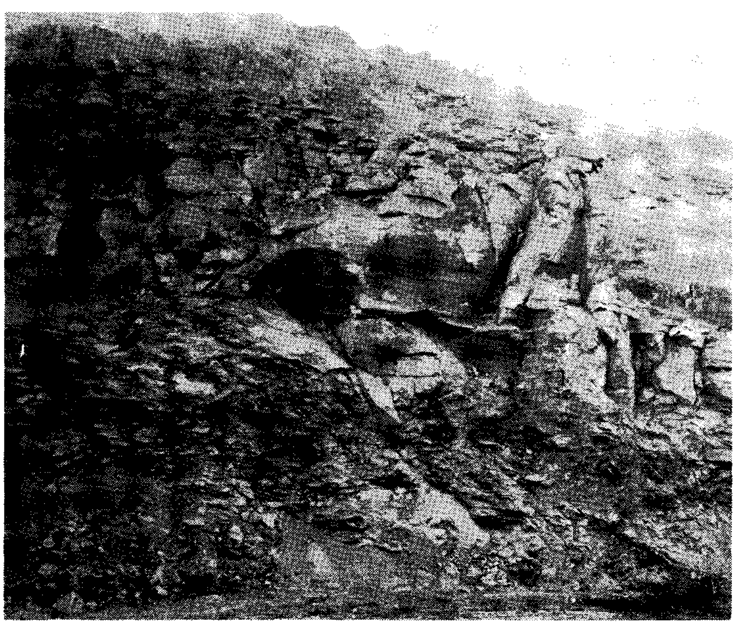


Figure 6.--As much as 80 percent of the material above Coal VII in Sullivan County consisted of massive sandstone and thick-bedded shale.

Table 10.--Total stocking per acre of a natural forest on Indiana coal-stripped lands[1/]

Size classes	Number of trees	Basal area	Volume	
	Number	Sq. ft.	Cu. ft.	Bd. ft.
Reproduction				
0-5 ft. tall	3,870	--	--	--
5 ft. tall - 4.5 in., d.b.h.	710	--	--	--
Total	4,580	--	--	--
Poles				
5-7 in., d.b.h.	29	5.6	60.4	--
8-10 in., d.b.h.	8	3.1	58.8	--
Total	37	8.7	119.2	--
Saw timber				
11-14 in., d.b.h.	10	8.6	85.4	536
15-18 in., d.b.h.	4	6.1	87.3	590
Total	14	14.7	172.7	1,126
Grand total	4,631	23.6	291.9	1,126

1/ Stripped about 30 years ago.

during periods of unusually heavy demand, this saw timber probably could not be marketed. Virtually the same low-quality characteristics were shown by the pole-sized trees. In addition, over half of the poles were of poor species, such as American elm, willow, persimmon, and sassafras.[7/] Although reproduction was abundant, 80 percent of it was of the less desirable species. These consisted of American elm, pin oak, shingle oak, black gum, sassafras, boxelder, and persimmon. The better species making up the remaining 20 percent were ash, black walnut, black cherry, northern red oak, hickory, and eastern red cedar.

In addition to the undesirable quality and species characteristics, the natural stand had the further fault of being poorly distributed over the area. Heavy-seeded species such as the oaks, black walnut, and hickory were largely confined to the outer portions of the stripped land. Saw-timber and pole trees occurred as scattered clumps or as individual trees, with reproduction fanning out from these seed sources (figs. 7 and 8). Many openings

7/ The common and scientific names of species mentioned in the text are listed in the Appendix.

between the patches of trees were covered with weeds, grasses, briars, and shrubs. The better timber species, commonly intolerant to shade, invade such cover with difficulty.

During the spring of 1951 a natural timber stand on strip-mined land in northern Illinois was examined. It was about the same age as the one examined in Indiana and exhibited many of the same undesirable features. The volume of saw timber was practically identical on the two areas. These data illustrate the kind of forest stands that may be expected when extensive coal-stripped lands are allowed to become forested through natural means. In Ohio, Merz and Plass (23) found good natural stocking on a narrow hillside stripping which lay below heavily wooded slopes. However, unless an abundant source of seed is at hand, invading tree reproduction of commercially important species will not adequately stock the land in a reasonable length of time. Similar conclusions were reached by Moore and Headington (24) from studies on stripped lands in eastern Ohio. A comparison of the Indiana stand with older plantations (pages 22-32) shows clearly that planting has many advantages.

Methods should be developed for converting these natural stands to more valuable forest cover. Studies dealing with methods of harvesting, species for interplanting, intensities and frequencies of release cuttings, and other cultural measures would provide much of the information needed to efficiently rehabilitate such natural forests.

OLDER FOREST PLANTINGS ON COAL-STRIPPED LANDS

Most of the forest plantings on strip-mined lands have been made within the past 10 years and information concerning their success is limited chiefly to early survival and growth. However, some Indiana companies began planting about 20 years ago. These older plantations provide opportunities for studying the later growth of planted trees and the development of forest conditions. With these objectives in mind, 23 older company-established plantations were studied in the fall of 1950.

SELECTION OF SAMPLE PLANTATIONS

Only the oldest plantations that could be found having fair or better survival were sampled. Poorly stocked or failed plantings were excluded because they would yield little reliable information on the actual capabilities of the site. Unknown factors such as poor selection of species, improper handling of stock, poor planting techniques, low-quality stock, or unfavorable weather conditions during and after planting could well have caused these failures.

Figure 7.--The forked, open-grown hickory pictured here illustrates the poor form found in many of the trees on naturally forested strip-mined lands.

Figure 8.--Nearly 30 years after mining, natural reproduction of trees on this stripped area in Sullivan County is spotty and composed mainly of the less desirable species.

The numerous old plantations of pure black locust also were excluded because of their general decadence from heavy borer infestation.

METHOD OF SAMPLING

A sample plantation was defined as one that was relatively homogeneous as to species and age of planted trees, date of stripping, and general mine-bank characteristics. Each area was sampled with 0.01-acre circular plots spaced mechanically along random lines running perpendicular to bank contours. A total of 302 sample plots was taken and for each plot the following information was recorded:

Planted trees	Natural tree reproduction	Bank material
Species	Species	Acidity and texture
Age	Age	Consistency
Total height	Total height	Relief
Merchantable height	D.b.h.	Slope percent
D.b.h.	Vigor	Erosion
Vigor	Topographic position	
Topographic position	Aspect	
Aspect	Crown class	
Crown class		

Within the sample plots, d.b.h. was measured on all trees taller than 17 feet. The merchantable height of planted trees only was estimated to a 3-inch top. In addition to the measurements listed above, increment borings were taken on one or more dominant or codominant planted trees in most plots to determine the age at which diameter growth had become retarded.

GENERAL DESCRIPTION OF PLANTATIONS

Plantations suitable for this study were found in nearly half of the strip-mining counties in the state (table 11). The banks on which they were located were predominantly acid loams containing high amounts of silt and clay. One of the three calcareous areas examined (Plantation Ve-2) had been graded almost level before being planted.

Thirteen different species of planted trees, ranging from 15 to 24 years of age, were represented in one or more of the plantations. The most extensively planted species were non-native pines. Of these, Scotch and Austrian pines were of exotic origin and others were introduced from northern states. Only a few hardwood plantings were found and they usually occurred as irregular

mixtures with pines. Except for black locust, the hardwoods were native to the locality in which they were planted. Early establishment records for these plantations indicate that black walnut and the oaks were hand-seeded directly on the banks.

Table 11.--Location, bank type, species, and age of plantations sampled

County	Plantation	Bank type	Species planted[1/] [2/]	Age
Clay	Cl-1	Acid sandy clay loam	YP, BW, BL, SWO, SP, RP, CO	22
	Cl-2	Acid sandy clay loam	RP, SP, JP, WP, BW	20
Greene	Gr-1	Acid shaly sandy loam	SP, RP, BL, JP	21
	Gr-2	Acid shaly sandy loam	SP, AP, JP, WC, WS	18
Owen	Ow-1	Acid silty clay loam	WP, WS	22
	Ow-2	Acid silty clay loam	JP	22
	Ow-3	Acid silty clay loam	JP, RP	22
Pike	Pi-1	Acid silty clay loam	RP, BW, SP, BL, RO, AP, SWO, CO, JP, WP	22
	Pi-2	Acid silty clay loam	BW	22
	Pi-3	Acid shaly silt loam	RP, SP, BW	21
	Pi-4	Acid shaly sandy loam	SP, AP, RP, BL, BW	20
	Pi-5	Acid sandy clay loam	JP, AP, SP	19
	Pi-6	Acid silty clay loam	WP	15
	Pi-7	Acid shaly sandy loam	SP, JP, WP, BL	15
Sullivan	Su-1	Acid sandy clay loam	AP, WP, JP, BL, YP	24
	Su-2	Acid sandy clay loam	JP	19
	Su-3	Acid sandy clay loam	SP, AP, BW	18
	Su-4	Acid sandy clay loam	RP, BL, WP, WC	16
Vermillion	Ve-1	Calcareous silt loam	SP	18
	Ve-2	Calcareous silty clay loam (graded)	BW	18
Vigo	Vi-1	Acid sandy loam	SP, AP, JP	21
	Vi-2	Acid sandy loam	JP, SP	21
	Vi-3	Calcareous sandy loam	BW	21

1/ Key to abbreviations:

AP - Austrian pine
JP - Jack pine
RP - Red pine
SP - Scotch pine
WC - Northern white cedar
WP - Northern white pine
WS - White spruce
BL - Black locust
BW - Black walnut
CO - Chestnut oak
RO - Red oak
SWO - Swamp white oak
YP - Yellow-poplar

2/ Species are listed in order of importance in the stand.

PLANTATION GROWTH AND DEVELOPMENT

One common method for estimating the forest productivity of an area is through the relative heights of dominant and codominant trees at a given age. Based upon this criterion and growth data on the sample plantations, the average site-quality of plantable banks in Indiana appears to be equal or superior to "good" sites on unmined land within the native range of species for which comparative data are available (fig. 9). At age 20 the northern pines have grown from 8 to 14 feet taller on stripped land than in better-than-average plantations in the Lake States region (27). Recent investigations have been made by Gaiser and Merz (10) into the growth of red and white pine plantations on old fields in the unglaciated region of Ohio and central Indiana. According to their results, the growth rate of these species on Indiana strip-mined land is similar to that found on old fields of intermediate site quality. Hardwoods planted in mixture with black locust on mine banks have grown at about the same rate as that reported for the same species planted without black locust on favorable unmined sites (11, 12, 30).

Three major types of species combinations were found in the survey: (a) pines, (b) mixed pines and hardwoods, and (c) hardwoods. These varied considerably in stand development and are discussed separately below.

Pine Plantations

The 15 pine plantations examined were composed essentially of five species of pine, often planted in irregular mixtures. Each of these species had peculiarities of growth which influenced the structure and productiveness of the stands. Jack and Scotch pines generally had the best survival and early growth. Much of the Scotch pine, however, was crooked and limby, and a number of the trees were partially or completely girdled by sapsucker drilling--a form of injury to which the exotic pines are especially susceptible (fig. 10). Austrian pine was rapid-growing but extremely limby, and the older trees showed a pronounced tendency to become short-boled. Because of their typically slow initial growth, red and white pine often were suppressed when planted in intimate mixtures with faster-starting species. However, their later growth rate, when they were not overtopped, has been comparable to that of the other pines. Northern white cedar and white spruce, which were mixed with pine in two plantations, had mostly failed and the surviving trees were growing very slowly.

Increment borings of 204 pine trees were made to determine the effect of species and density of stocking upon the age at which diameter growth had slowed down. Jack pine, white pine, and to a lesser extent, red pine, showed considerable response to stand

density (fig. 12). For a given density, the age of retardation varied among species because of inherent differences in growth rate and tolerance. Thus, with 800 trees per acre, the diameter growth of jack pine was slowed down by stand closure at about 9 years of age, red pine at 10 or 11 years, and white pine at 12 years. Correlation between density and retardation age was highly significant[8] for jack and white pine, but was not significant for red pine. It is probable that more samples of the latter species would have resulted in a regression line approximately parallel to those of the other two.

The low correlation coefficients (0.5 or less) obtained for these pines indicate that the initial slowing down of diameter growth on spoils is often due to factors other than stand competition. Some of the sample trees which were entirely in the open were found to have decreased in growth rate at an early age. Probably the presence of nearby detrimental material restricted root development of these trees. High acidity or high rock content might be suspected from the failure of the surrounding stand.

For Scotch and Austrian pines the age of growth retardation was influenced but slightly by stand density in comparison with the other pines. Since all of the pines were planted on essentially the same areas, the lesser response of exotic species to different stocking levels may be due to further limitations on growth imposed by unfavorable climatic conditions.

The pine plantations generally had survived better than the other two plantation types and, on the average, contained more than 800 trees per acre (fig. 11). In the 18- to 22-year-old stands, the planted trees had an average basal area of 82 square feet per acre and contained about 850 cubic feet of merchantable material. If these stands were cut at the present time, they would yield nearly a thousand 7-1/2-foot posts per acre (table 12).

Accurate records were kept by Sawyer (29) for a small experimental cutting made in the spring of 1951 in Plantation Pi-4, a 20-year-old stand composed chiefly of Scotch and Japanese red pines. Here a representative area of 0.9 acres was clearcut to make way for expanding coal preparation facilities. A total of 3,973 lineal feet of posts and poles were cut (table 13). These products were skidded from the banks by horse, peeled by hand at the landing, and sold on the market for $302.03. Although immature, this plantation yielded an average gross return of about $17 per acre per year.

8/ The term "highly significant" indicates that the probabilities are 99 out of 100 that the results are not due to chance. Regression formulas and correlation coefficients are given in the Appendix. These statistical tests are measures of the dependability of the results.

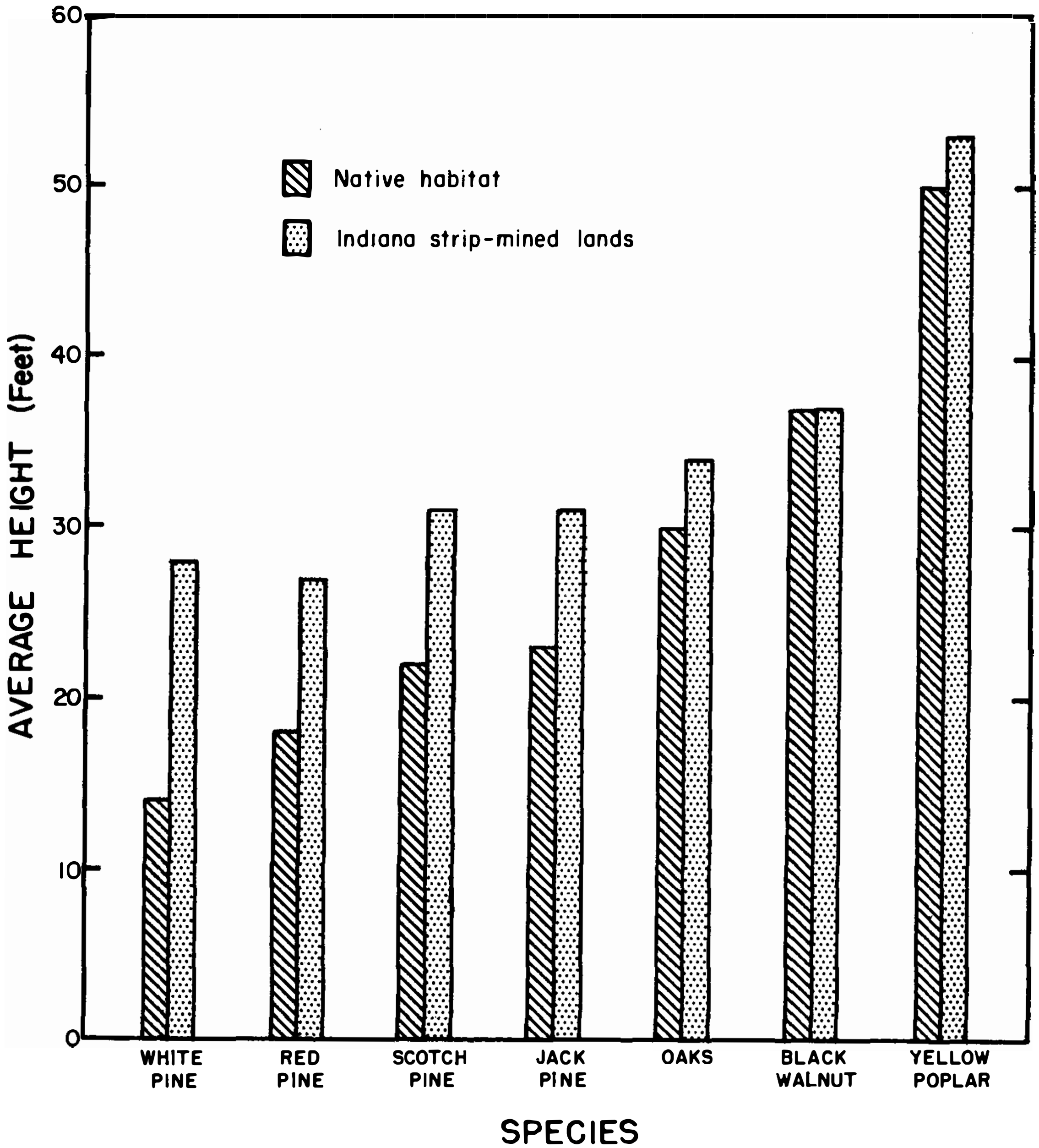


Figure 9.--Average height of dominant and codominant trees at 20 years of age on good sites in their native habitat as compared with their height on Indiana strip-mined lands.

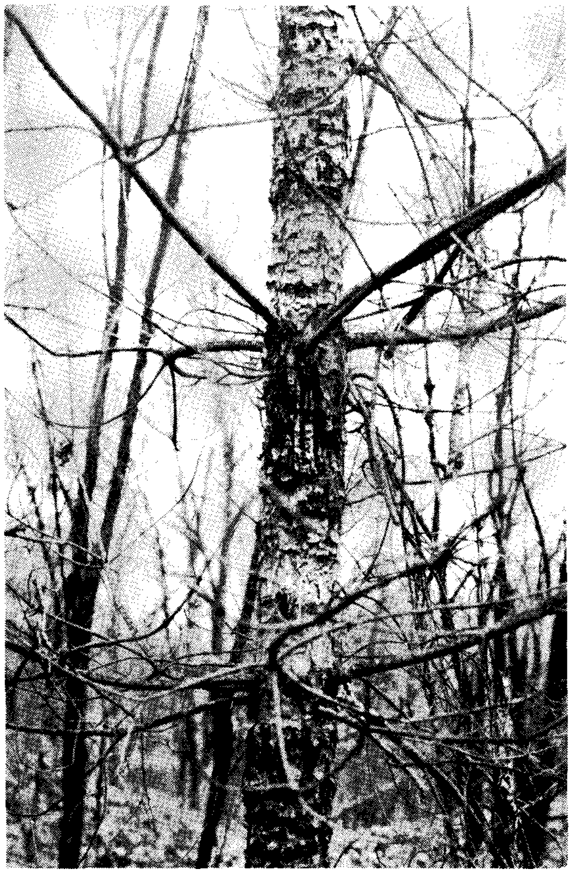


Figure 10.--Drilling by sapsuckers often causes severe injury to Scotch and Austrian pines. Occasionally the trees are completely girdled and killed.

Figure 11.--A well-stocked pine stand planted 20 years previously on acid loam banks in Pike County. A part of this plantation was clearcut experimentally and produced 487 posts and poles per acre.

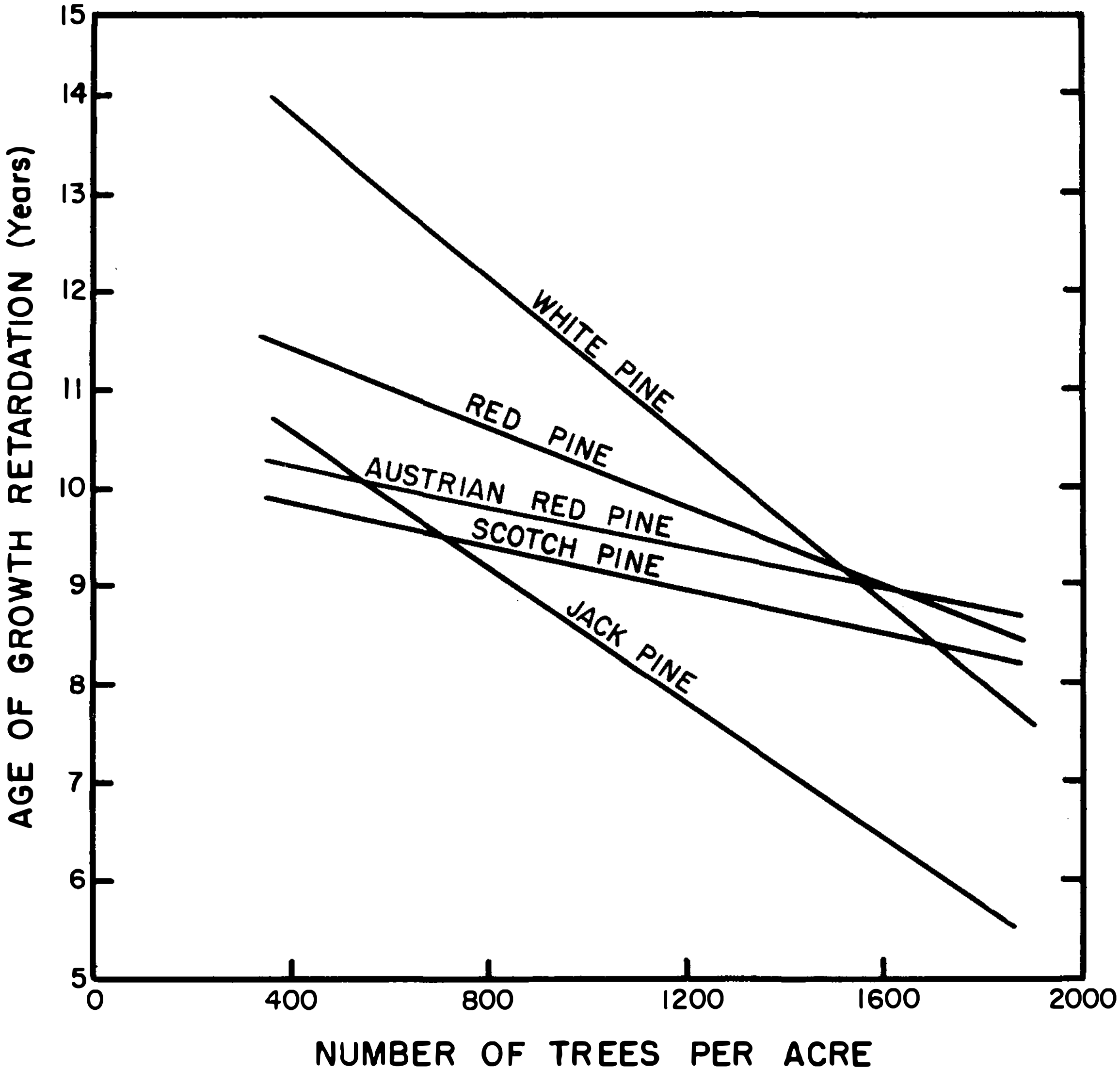


Figure 12.--Effect of stand density upon age at which diameter growth is retarded in five pine species planted on Indiana stripped lands.

Table 12.--Average age, stocking, and merchantable volume of sample pine plantations

Plantation area	Age	Stocking per acre		Merchantable volume[1] per acre	
		Trees	Basal area[2]	Cubic volume	7½-foot posts
	Years	Number	Sq. ft.	Cu. ft.	Number
Ow-1	22	525	75.8	640	640
Ow-2	22	1,033	96.7	1,105	1,583
Ow-3	22	1,200	96.7	1,117	1,533
Vi-1	21	488	71.7	968	961
Vi-2	21	633	51.7	498	733
Pi-3	21	833	60.0	412	450
Cl-2	20	1,149	112.0	998	1,240
Pi-4	20	966	84.0	704	766
Pi-5	19	884	93.3	770	900
Su-2	19	583	43.9	704	766
Gr-2	18	760	108.0	1,226	1,140
Su-3	18	925	93.3	1,169	1,358
Ve-1	18	600	73.9	640	583
Average	--	814	81.6	842	973

1/ Volume of planted trees only, based upon a minimum top diameter of 3 inches, inside bark.

2/ Does not include intermediate or suppressed trees less than 17 feet tall, or natural reproduction.

In the example cited above, the returns were not sufficient to cover the costs of the operation because: (1) inexperienced labor was employed at mine wages; (2) time-consuming peeling was done by hand; and (3) Scotch and Japanese red pine proved to be difficult species to handle because of their branchiness and relatively tight bark. Sawyer (29) concludes that even on this small area a net profit probably could have been obtained by hiring experienced woods workers on a piece-rate basis and by using a mechanical peeler.

Up to the present, the growth rate and development of pine plantations having reasonably good initial survival have generally been excellent on stripped land. However, there are good indications that the exotic species, Austrian and Scotch pines, will never produce good-quality saw timber. The influence of soil or climate might reduce the initial rapid height growth of the northern pines also as the stands become older, but so far this has not been observed here. On prairie soils in northern Illinois, Lorenz and Spaeth (19) found that the growth rate of planted white pine, as

Table 13.--Products harvested from a small (0.9-acre) experimental cutting on a strip-mined area in Indiana[1]

Product	Length	Top diameter (inches) 3-4	4-5	5 plus	Total
	Feet	Number of pieces			
Posts	6.5	28	10	5	43
	7.0	82	72	23	177
	7.5	49	44	14	107
	8.0	35	23	17	75
	Total	194	149	59	402
Corner braces	10.0	28	18	6	52
	12.0	0	5	0	5
	Total	28	23	6	57
Poles	16.0	15	1	0	16
	18.0	11	0	1	12
	Total	26	1	1	28

1/ Part of a 20-year-old Scotch and Austrian pine plantation was clearcut in this test (Pi-4, table 11).

well as that of Scotch pine, European larch, and Norway spruce, declined abruptly when the plantations reached 20 to 25 years of age.

Natural reproduction within the pine plantations was sparse and poorly distributed. Most of the species invading these areas are relatively intolerant to shade and probably will not become established under the pine canopy. Over four-fifths of the volunteer trees consisted of recently germinated seedlings less than 2 feet tall (table 14). About nine-tenths of these were pine (chiefly jack and Scotch), black cherry, and shingle oak. The basal area of naturally reproduced trees 17 feet or more in height averaged 3.2 square feet per acre. The larger trees were mostly scattered cottonwood, elm, cherry, and sycamore which had seeded in before or shortly after the area was planted. Because of their early start and rapid growth, many of them have become dominant, spreading wolf trees that have suppressed adjacent pine. Successful establishment of other volunteer species, such as ash and the oaks, was generally limited to thinly stocked areas where some of the planted pine had failed.

Table 14.--Average number of volunteer trees per acre, by species and height class, in pine plantations

Species	Height class (feet) 0-1	2-5	6-16	17 or more	Total
	- - - - - -	- - -	Number of trees	- - -	- - - - - -
Black cherry	171	4	4	3	182
Pine[1]	41	0	0	0	41
Shingle oak	25	2	0	0	27
American and slippery elm	1	1	3	3	8
Cottonwood	0	0	1	6	7
Green and black ash	0	2	3	1	6
Northern red oak	4	0	0	1	5
Black oak	3	1	0	1	5
Eastern red cedar	3	1	0	0	4
Sassafras	0	2	1	0	3
Red maple	1	0	0	1	2
Sycamore	0	0	0	2	2
Chinquapin oak	2	0	0	0	2
White oak	1	0	0	0	1
Black willow	0	1	0	0	1
Boxelder	0	1	0	0	1
Miscellaneous[2]	1	1	1	0	3
Total	253	16	13	18	300

1/ Predominantly jack and Scotch pine.
2/ Includes red mulberry and redbud.

Mixed Pine and Hardwood Plantations

Four of the sample plantations, ranging from 21 to 24 years of age, contained irregular mixtures of pines and hardwoods. Although these differed considerably in species composition (table 15), their early development was in marked contrast to that of the pure pine plantations.

In the pine plantations, mortality often was restricted to small patches of adverse spoils and the openings thus created had relatively little effect upon the average growth of the remaining trees. In the mixed pine-hardwood plantations, the stands had opened up more extensively and uniformly. This was due, in part, to planting species with widely differing growth rates next to one another. As a result, some of the pines were overtopped and killed by the rapid initial growth of black locust. Elsewhere, other hardwoods died from early suppression by the pines (figs. 13 and 14). Subsequent deterioration of black locust from borer injury caused further opening of the stand.

Table 15.--Number of planted trees per acre in mixed pine-hardwood plantations by species and location

Species	Plantation			
	Su-1	Cl-1	Pi-1	Gr-1
	Number			
Pines				
Austrian pine	250	0	13	0
Jack pine	44	0	9	83
Red pine	0	40	133	183
Scotch pine	0	33	42	217
White pine	156	0	25	0
Total	450	73	222	483
Hardwoods				
Black locust	194	60	75	100
Black walnut	0	153	196	0
Chestnut oak	0	13	29	0
Red oak	0	0	38	0
Swamp white oak	0	60	33	0
Yellow-poplar	25	67	9	0
Total	219	353	380	100
Total - all species	669	426	602	583

The hardwoods, other than black locust, usually were superior in form and quality of growth to interplanted pines (fig. 15). On the average, about 60 percent of the surviving pine were intermediate or suppressed trees. They tended to be extremely crooked as a result of early whipping by black locust. The dominant or codominant pines were more or less open-grown and often had developed into coarse-limbed wolf trees.

Because of lower stocking, the mixed plantations have maintained a more rapid diameter growth than have the pine plantations. At 21 to 24 years of age, the mixed stands averaged 79 square feet of basal area and about 900 cubic feet of merchantable volume per acre (table 16). In spite of the lower survival, these results are similar to those reported for pine plantings of nearly equal age. However, on the average, pine-hardwood mixtures would yield considerably fewer posts than the pine plantings if cut at the present time.

Figure 13.--A 24-year-old mixed pine-hardwood plantation on acid sandy clay loam banks in Sullivan County, with Austrian pine in the foreground and black walnut and black locust in the background. The heavy ground cover in the opening is typical of this type of planting.

Figure 14.--Overtopping by hardwoods and, possibly, toxic effects of adjacent black walnut have caused considerable pine mortality in this mixed planting.

Table 16.--Average age, stocking, and merchantable volume per acre of mixed pine-hardwood plantations on strip-mined land

Plantation	Age	Stocking		Merchantable volume[1]	
		Trees	Basal area[2]	Cubic volume	Posts
	Years	Number	Sq. ft.	Cu. ft.	Number
Su-1	24	669	65.6	620	562
Cl-1	22	426	78.1	1,060	786
Pi-1	22	602	77.2	678	634
Gr-1	21	583	95.1	1,238	1,050
Average	--	570	79.0	899	758

1/ Volume of planted trees only, based upon a minimum top diameter of 3 inches, inside bark.

2/ Does not include intermediate or suppressed trees less than 17 feet tall, or natural reproduction.

Natural tree reproduction was about as sparse as in the pure pine plantations (table 17), but was somewhat better distributed over the areas. Only about half as many seedlings under 2 feet in height were found, chiefly because competition from typically heavy cover of weeds and briars limited the establishment of pine and black cherry. Other invading species, such as the oaks, were more widely represented and grew more successfully in the mixed plantations. Volunteer tree reproduction 17 feet or taller had an average basal area of 6.5 square feet per acre--slightly over twice that found in the pine plantations. Some of the planted hardwoods were suppressed by large dominant cottonwoods and sycamores, but generally they were less affected by overtopping from older natural reproduction than were the planted pines.

Hardwood Plantations

Three hardwood plantations, consisting entirely of black walnut and ranging from 18 to 22 years old, were examined. Widely differing bank characteristics among these areas were responsible for much of the variation in growth of the planted trees. In all cases the pure walnut plantings had grown poorly in comparison with the other plantation types and most of the trees were too small to contain merchantable material (table 18). The most successful plantation (Pi-2) was located on acid silty clay loam banks (fig. 16) and had an average basal area of 55 square feet per acre. Merchantable volume averaged about 230 cubic feet per acre. The poorest growth was found on predominantly calcareous material which had a high sand content (fig. 17). The average basal area of dominant and codominant trees in this stand (Vi-3) was less than 15 square feet and no merchantable volume was present.

Table 17.--Average number of volunteer trees per acre by species and height class in mixed pine-hardwood plantations on strip-mined land

Species	Height class (feet) 0-1	2-5	6-16	17 or more	Total
	- - - - - - -	Number of trees	- - - - - - -		
Shingle oak	32	28	5	0	65
Red oak	30	15	1	0	46
Black cherry	26	8	3	8	45
Pine[1/]	26	3	4	0	33
Chinquapin oak	10	4	0	0	14
Red maple	0	3	8	2	13
Black oak	8	3	0	0	11
American and slippery elm	0	0	5	5	10
Cottonwood	0	1	0	7	8
River birch	0	0	5	2	7
Boxelder	0	5	0	0	5
White oak	1	1	0	2	4
Sycamore	0	0	0	3	3
Black willow	0	0	0	2	2
Miscellaneous[2/]	0	4	0	0	4
Total	133	74	31	32	270

1/ Predominantly jack and Scotch pine.
2/ Includes sassafras, hackberry, and swamp white oak.

Table 18.--Average age, stocking, and merchantable volume per acre of pure black walnut plantations on strip-mined lands

Plantation	Age	Stocking: Trees	Stocking: Basal area[2/]	Merchantable volume[1/]: Cubic volume	Merchantable volume[1/]: Posts
	Years	Number	Sq. ft.	Cu. ft.	Number
Pi-2	22	825	55.0	232	417
Vi-3	21	983	14.5	0	0
Ve-2	18	608	23.0	105	67

1/ Volume of planted trees only, based upon a minimum top diameter of 3 inches, inside bark.
2/ Does not include intermediate or suppressed trees less than 17 feet tall, or natural reproduction.

Figure 15.--At 22 years, red oak in this mixed plantation on acid banks averaged 6.6 inches d.b.h., and was more than 40 feet tall.

Figure 16.--The best growth of pure black walnut plantings was found in this 22-year-old plantation on acid silty clay loam. The sparse ground cover under walnut is in sharp contrast to that commonly found under pine-hardwood mixtures.

Growth of Plantation Ve-2, located on calcareous silty clay loam banks that had been graded to a nearly level surface (fig. 18), was intermediate between that of the other two sampled plantings.

Black walnut did not grow as well in the pure stands as it did in mixtures with other species. In the pine-hardwood plantations the average height and diameter of dominant and codominant walnut were about 50 percent greater (table 19). One of the causes of slower growth in the pure stands may be the production of a toxic substance by walnut which inhibits the development of many plants (3). On ungraded banks especially, much of the surface under the planted trees was barren and unprotected by ground vegetation or litter. Less than one-fifth as much volunteer tree reproduction was present in the pure black walnut stands as in the pine or pine-hardwood plantations. The species represented and their average number per acre were as follows:

Black cherry	23
Cottonwood	10
American and slippery elm	6
Shingle oak	3
Red oak	7
Black ash	3

Only the dominant cottonwoods were over 17 feet tall and these averaged 2.8 square feet of basal area per acre.

Table 19.--Average d.b.h. and total height of dominant and codominant black walnut in pure and mixed plantings on strip-mined land

Plantation	Age	Dominant and codominant trees: Average height	Dominant and codominant trees: Average d.b.h.
	Years	Feet	Inches
Pure black walnut			
Pi-2	22	27	3.4
Vi-3	21	15	1.6
Ve-2	18	18	3.2
Mixed pine-hardwood			
Cl-1	22	44	5.8
Pi-1	22	35	4.4

MAJOR ENVIRONMENTAL FACTORS AFFECTING LATER PLANTATION SUCCESS

Recently established experimental plantings have yielded considerable information about the characteristics of stripped land that cause high plantation mortality. Among the principal factors are acid-toxicity, insufficient soil-sized material, erosion, and exposure. However, where these factors are not so injurious as to cause death, little has been known of their influence upon the later development of the planted trees. Some of this information is provided by data from the survey of older plantations in Indiana.

Acidity

Within any one area the haphazard distribution of patches of highly acid bank material makes it almost impossible to determine the average conditions surrounding an individual tree. However, the proportions of the total plantation area which fall into broad acidity classes can be estimated fairly accurately. The effect of these differing proportions among areas should then be reflected in the average growth rate of the trees planted on these areas.

Pine plantations did not appear to be affected by variations in acidity above pH 4.5. However, higher acidities (below pH 4.5) caused a definite decrease in their growth rate.[9] On those areas where highly acid surface material occupied 10 percent or more of the area, the mean annual height growth of the pine plantation was reduced by about 0.3 feet (table 20). All species of pine reacted about the same to the highly acid conditions.

Table 20.--Effect of high acidity upon the mean annual height growth of dominant and codominant pines, by species

Species	Percentage of area below pH 4.5	
	0-10	10 or more
	Feet	Feet
Jack pine	1.7	1.5
Japanese red pine	1.7	1.2
Red pine	1.7	1.3
Scotch pine	1.8	1.4
White pine	1.5	1.4
Average	1.7	1.4

9/ Statistical tests indicate that the probabilities are 19 out of 20 that the results are not due to chance.

Figure 17.--Coarse-textured sandy banks make poor planting sites for black walnut. This 21-year-old walnut planting was made on this type of stripped land. It has averaged only 0.7 feet of height growth per year.

Figure 18.--Pure black walnut planted on graded calcareous loam banks in Vermillion County. At age 18, height growth has averaged 1 foot per year.

The effects of acidity on hardwood species could not be analyzed because of their limited occurrence in the sample plantations. General observations and studies reported by other investigators indicate that high acidities may be even more detrimental to hardwoods than to pines (20).

Topography and Texture

As in hilly sections of unmined forest lands, the topography of strip-mined lands introduces variations in moisture conditions and exposure which affect tree growth. In the sampled plantations, trees growing on the lower slopes of the banks were nearly always taller than those on the drier, more exposed portions near the ridge tops (fig. 19). Valid differences in response among species could not be determined from the data available.

The effect of varying heights of banks and texture of bank material was obtained by dividing the banks of each sample plantation into two relative height classes--"low" banks and "high" banks. Within the ranges of bank heights found, only on sandy-textured banks did the trees show a noticeable reduction in growth on upper slopes of the higher banks[10] (table 21). These results indicate that it is advisable to plant species adapted to dry site conditions on the upper portions of exceptionally high banks. This is especially true for banks containing much sand or other coarse material.

Table 21.--Effect of bank height upon the average annual height growth of dominant and codominant trees planted on upper slopes and ridges

Textural classes	Low banks		High banks	
	Bank height	Height growth	Bank height	Height growth
	- - - - - - - - - - -	- - - - Feet-	- - - - -	- - - - -
Sandy loam	19	1.7	26	1.5
Sandy clay loam	9	1.6	18	1.3
Shaly sandy loam	9	1.5	15	1.4
Silty clay loam	9	1.3	15	1.3
Average	11	1.5	18	1.4

Surface materials in the sampled plantations consisted mainly of friable loams, and extremes of coarse sand or fine-textured clay were not encountered. Most of the rock exposed by

10/ Statistical tests indicate that the probabilities are 99 out of 100 that the results are not due to chance.

stripping in Indiana is made up of easily decomposed shales and sandstones, and original differences in surface rock content have largely been obliterated by weathering. Because of the limited variation in texture encountered, its effects upon moisture availability, aeration, and root development were not readily apparent in the growth of the plantations.

Erosion

Severe erosion on the slopes and deep sedimentation in the valleys are common causes for early death of seedlings planted on barren strip-mined lands (fig. 20). However, on most of the older plantation areas the banks were found to be well stabilized, and erosion injury to established trees was restricted primarily to exceptionally steep banks exceeding 65 percent in slope. A heavy mat of needles, up to 2 or 3 inches thick, usually had accumulated under the pine stands (fig. 21). Under the pine-hardwood mixtures, especially those containing black locust, abundant litter and ground vegetation provided excellent protection against erosion and sedimentation (fig. 22). A slight amount of erosion was still occurring in the pure black walnut plantations because of the characteristic sparseness of ground cover. However, few of the trees had been noticeably affected.

PLANTATION MANAGEMENT ASPECTS

In addition to providing estimates of the forest growth potentialities of strip-mined lands, the survey of older plantations sheds some light on the management practices needed to maintain a high rate of productivity in these and similar young forests. The need for such information will become increasingly urgent as thousands of acres of young plantations on stripped lands develop into valuable forest stands.

Protection

The prerequisites of forest management are protection from fire, grazing, insects, and diseases. Because of the relatively isolated condition of most strip-mine plantings, damage from fire or grazing is rare. However, as the plantations mature and the areas are used more intensively by campers, hunters, and fishermen the danger of fire will increase and modern control measures will become necessary. The maintenance of old haulage roads and secondary roads would greatly facilitate fire suppression, management activities, and harvesting of products. Plantations containing exotic or off-site species probably will be quite susceptible to injury from insects, diseases, or other related agencies (fig. 10). Control measures, such as sanitation cuts and airplane spraying

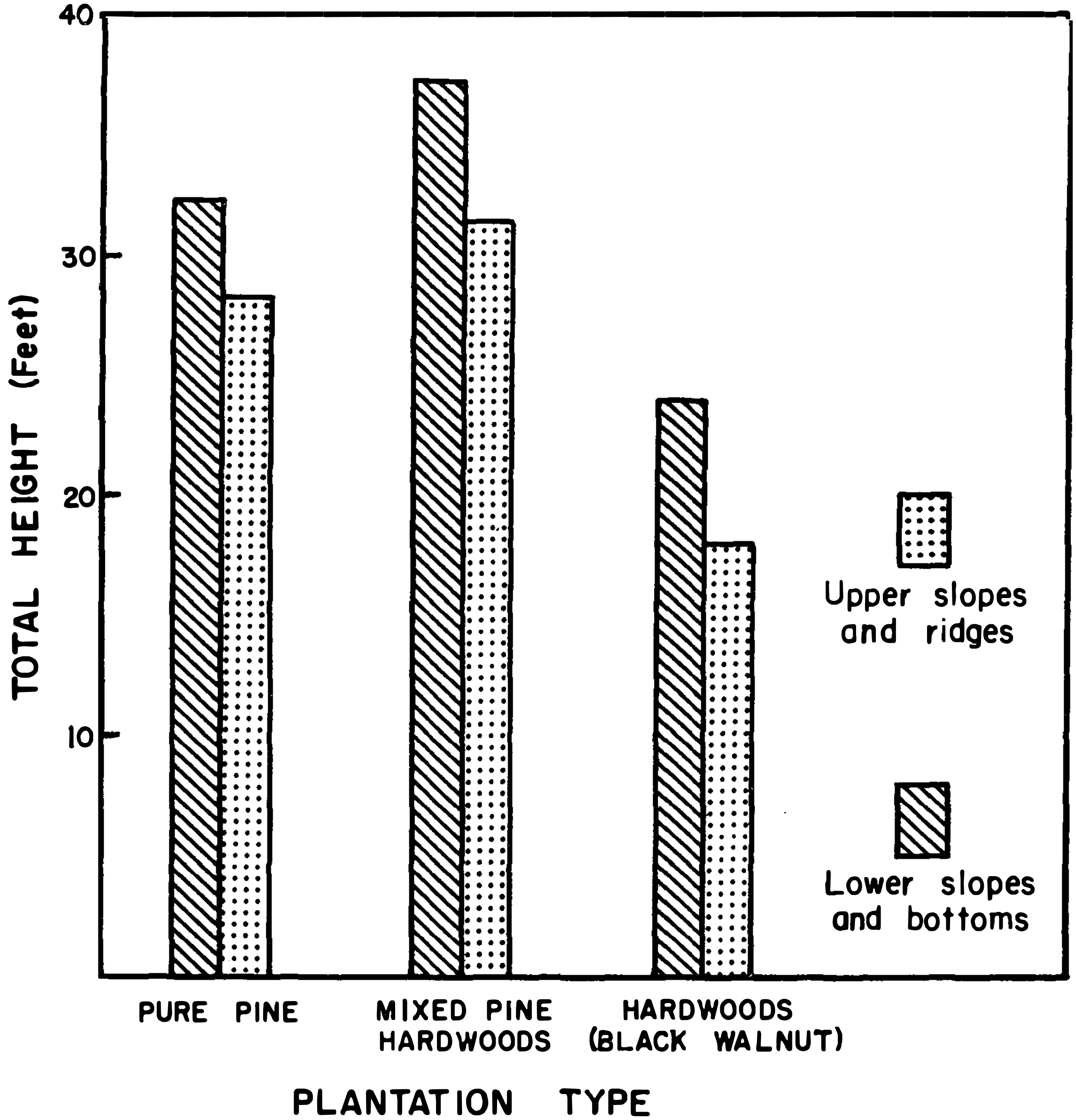


Figure 19.--Effect of topographic position upon the average total height of dominant and codominant trees at 20 years of age on Indiana strip-mined lands.

Figure 20.--Rapid gullying is causing serious root exposure of these planted black locust and has been responsible for the failure of species planted adjacent to the locust. Banks composed mainly of glacial till, such as these in Vermillion County, are especially susceptible to severe erosion.

Figure 21.--A thick mat of needles commonly develops under pine plantations, reducing erosion and moisture evaporation, and providing much-needed organic matter.

Figure 22.--A 20-year-old plantation of borer-riddled and decadent black locust. These trees will not produce merchantable material but the luxuriant growth of briars and weeds attest to improved site conditions. Excellent protection against erosion and sedimentation also is provided by such dense ground cover.

may be desirable in case of light or spotty attacks. Where attacks become epidemic, it may be advisable to cut all marketable trees and replant with more suitable species.

Cultural Treatments

In most of the plantations examined the rate and quality of growth could be greatly improved by thinning and pruning. This was especially true in the more heavily stocked pine plantations. The best time for conducting these operations appears to be when the trees are about 18 to 20 years of age. Delaying the first thinning beyond the age at which growth becomes retarded (fig. 11) may cause some loss in growth, but some merchantable products may then be obtained. By thinning from "above" and taking the larger, poorly formed trees, it may be possible to at least liquidate costs with products removed (fig. 23). Large, overtopping trees, such as cottonwood and sycamore, also should be cut, or, if unmerchantable, they should be girdled. Other volunteer trees, especially those of desirable species, should be left as future seed sources for restocking the area after the plantation is harvested.

Trees 18 to 20 years old usually will be tall enough to be pruned to a height of 17 feet to permit the growth of a clear butt log. Pruning at this time may be limited to about 200 well-spaced trees per acre which have been selected as potential crop trees. These should be straight and healthy with vigorous crown development. It may sometimes be profitable to prune an even larger number of trees in the plantation. In later thinning operations, the absence of knots will permit yields of more valuable products and will result in easier peeling. The growth-quality of conifers usually is benefitted more by pruning than is that of hardwoods.

Regeneration

One of the more important objectives of forest management is to provide for repeated forest crops through natural regeneration. On Indiana strip-mined land, the tree reproduction found invading the natural forest and the older plantations from outside sources was found to consist principally of undesirable species. This indicates that the maintenance of a desirable forest will depend largely upon the ability of planted trees to reproduce and establish themselves (fig. 24). Further research is needed to develop management and harvesting techniques that will favor reproduction of the better species.

Since hardwoods tend to supersede pines in this region, the plantations containing pine probably will be converted, by natural succession, to a predominantly hardwood type. It appears that pure pine plantations will be succeeded mainly by inferior hardwoods

invading from outside sources. For this reason most present-day plantings on stripped lands should include mixtures of desirable native hardwoods which can later provide enough seed to maintain a good stand composition.

In the past, extensive areas of strip-mined land in Indiana were planted with pure black locust. Nearly all of these plantations have been made unmerchantable by heavy borer damage but the productive capacity of the banks has been greatly improved (fig. 23). To make use of this increased growth potential, many of these decadent plantations can be successfully underplanted with other, more valuable hardwoods. Since the locust present will act as trainers, only about half as many trees would need to be underplanted as would normally be used on barren banks. Where a very heavy growth of weeds and brush exists, underplanting of the locust is not recommended without prior treatment to reduce competition. Research is needed to determine the value of cutting, burning, and poisoning as possible methods of getting rid of the competing vegetation.

FOREST PLANTING EXPERIMENTS

In addition to studying the extent and character of coal-stripped lands, the development of older company plantings, and the characteristics of natural forests, the Central States Forest Experiment Station has started a series of forest planting experiments on Indiana stripped lands. These studies, conducted in cooperation with the Indiana Coal Producers' Association and member mining companies, deal with species adaptation and with the effects of black locust upon other planted hardwoods.

SPECIES ADAPTATION

Early in the investigation of coal-stripped lands in the Central States, the need for more information on the species best suited to planting became apparent. One of the first research studies of species adaptation was established in Indiana during 1945. This was followed by a second series of experiments in 1947 and by a third series in 1949. The more important results of these studies are reported here.

1945 Experiment

For this study plantings were established at two locations. One was located near Boonville, Warrick County, in the unglaciated region and on stripped lands derived from mining Coal V. The surface material was predominantly thin-bedded shale with some

Figure 23.--Merchantable posts and poles were removed efficiently from this 20-year-old pine plantation in Pike County by horse-skidding.

massive, acid sandstone and a high proportion of soil-sized particles. A large part of the area developed highly acid conditions after planting. Tests made in 1947 revealed a pH range of 2.6 to 8.2, with 12 percent of the tests showing a pH below 4.

The second experimental planting was established near Riley, Vigo County, in the Illinoian glaciated region. This land was stripped by a tandem operation in 1941 for Coal V and the resulting banks were predominantly calcareous with very few toxic-acid spots. The surface material was classed as stony silt loam, having about 45 percent thin-bedded shale, 40 percent soil-sized particles, and 15 percent massive limestone and sandstone.

Duplicated plots, 1/4 to 1/2 acre in size, of six coniferous species and five hardwood species were planted in each of the two locations. At Boonville the conifers were established as pure plantings only, while at Riley both pure and mixed coniferous plantings were made. On both areas cottonwood, sweet gum, and soft maple were planted alone and in 25 and 75 percent mixtures with black locust. Red oak and yellow-poplar plantings on both areas were made only in 25 and 75 percent mixtures with black locust. The interplantings with locust are discussed in a later section.

After four growing seasons the over-all survival of all species in pure plantings at both locations was 44 percent[11/] and tree height averaged 2.8 feet (table 22). The conifers survived much better than the hardwoods, but were not quite as tall after the first four seasons. Survival was better on the Riley plots than on those near Boonville; however, somewhat better growth was obtained on the Boonville area. Neither survival nor growth has been as good as expected. The development of highly acid conditions accompanied by flooding of some of the plantings account for the low survival and slow growth on the Boonville area. On the Riley area many of the planted trees were repeatedly clipped off and girdled by rabbits. This damage probably is responsible for the low survival and growth obtained there.

The mixed conifer plantings on the Riley area consisted of mixtures of pitch, jack, red, shortleaf, Virginia, and white pines. At the end of four growing seasons there were no practical differences in survival and growth between the mixed coniferous plantings and the pure plantings of the same species.

11/ The survival figures for this experimental planting and for those which follow exclude mortality caused by toxic-acidity. Therefore, similar results may be expected in regular field plantings where toxic spots are recognized and avoided.

Table 22.--Average fourth-year survival and height of pure plantings on stripped lands near Riley and Boonville, Indiana

Species	Survival			Total height		
	Riley	Boon-ville	Both	Riley	Boon-ville	Both
	- - - Percent- - -			- - - - Feet - - - -		
Hardwoods						
Cottonwood	52	45	49	5.4	5.6	5.5
Sweet gum	13	7	10	1.7	2.7	2.2
Soft maple	5	46	25	2.3	4.8	3.6
Average	23	33	28	3.1	4.4	3.8
Conifers						
Jack pine	81	47	64	3.1	2.7	2.9
Loblolly pine	(1/)	21	21	(1/)	3.4	3.4
Pitch pine	55	57	56	1.6	2.7	2.2
Red pine	49	48	48	1.2	1.5	1.3
Shortleaf pine	52	46	49	2.4	2.2	2.3
Virginia pine	79	18	49	3.4	2.6	3.0
White pine	72	(1/)	72	1.6	(1/)	1.6
Average	64	39	52	2.2	2.5	2.4
Average - All species	51	37	44	2.5	3.1	2.8

1/ Not planted.

1947 Experiment

During the spring of 1947, six species-adaptation plantings were made on stripped land in Vermillion County, within the Wisconsin glaciated region (fig. 25). Four of the plots were located near St. Bernice and two near Centenary. The bank materials removed from above Coal VI were composed mainly of calcareous glacial till. About two-thirds of the bank surface was made up of soil-sized particles. Sample pH tests showed a range of 7.0 to 8.5. The plots were planted with eight species of hardwoods and eight species of conifers. They were examined for survival and growth at the end of the fifth growing season.

Over-all survival was 53 percent and the average total height of all species, except black locust, was 2.6 feet (table 23). The hardwoods had a higher average survival and height than the conifers. If shortleaf and loblolly pines, which had a very low survival, are

Figure 24.--Natural reproduction, such as is being seeded in by this 19-year-old planted jack pine in Sullivan County, often successfully invades adjacent barren or sparsely vegetated banks.

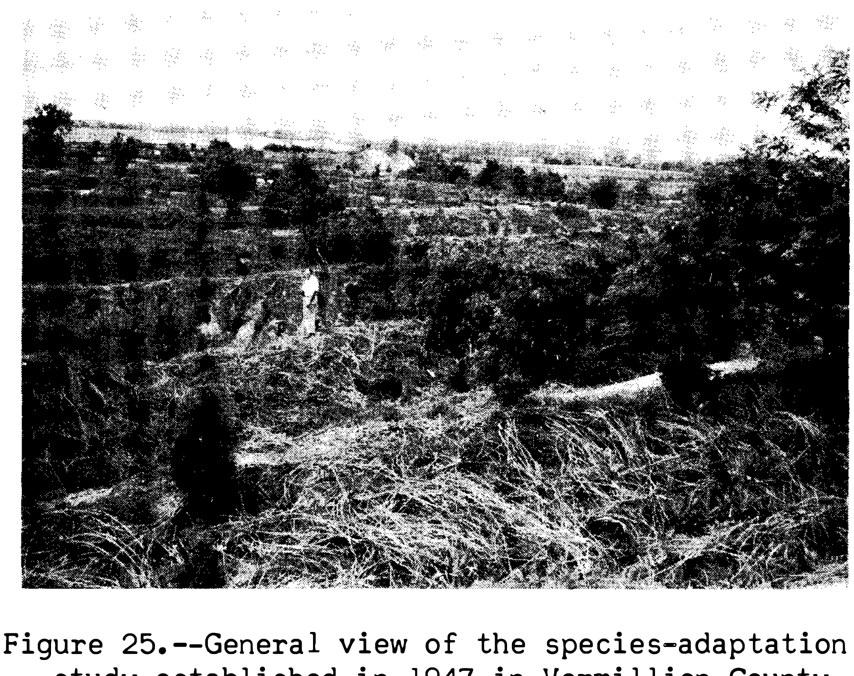


Figure 25.--General view of the species-adaptation study established in 1947 in Vermillion County.

omitted from the averages, survivals of the two species groups are practically identical. Note that survival is somewhat better on these plots than at Riley and Boonville but that total height is nearly the same.

Table 23.--Average fifth-year survival and height of experimental plantings on calcareous banks in Vermillion County, Indiana

Species	Survival			Total height		
	St. Bernice area	Centenary area	Both areas	St. Bernice area	Centenary area	Both areas
	- - - -Percent- - - -			- - - - Feet - - - -		
Hardwoods						
Ash	92	91	92	2.8	3.1	3.0
Black locust[1/]	--	--	--	--	--	--
Black walnut	19	53	36	1.6	1.6	1.6
Black walnut seed	75	64	64	1.6	1.9	1.7
Cottonwood	61	74	63	6.2	5.1	5.7
Osage orange	57	71	64	2.9	3.8	3.3
Sweet gum	45	71	58	2.3	2.2	2.3
Soft maple	69	66	67	3.5	3.7	3.6
Yellow-poplar	14	40	27	1.9	2.4	2.1
Average	54	66	60	2.8	3.0	2.9
Conifers						
Jack pine	75	70	73	2.8	2.9	2.9
Loblolly pine	5	8	6	2.2	2.5	2.3
Pitch pine	77	64	71	2.2	2.2	2.2
Red pine	52	62	57	1.4	1.2	1.3
Shortleaf pine	2	2	2	1.9	1.2	1.6
Virginia pine	44	33	38	2.5	2.6	2.5
White pine	44	36	40	1.1	1.1	1.1
Red cedar	71	82	77	3.1	3.6	3.4
Average	46	45	45	2.2	2.2	2.2

1/ Not all of the black locust were examined, but sample measurements indicated an average survival of over 95 percent and average height of 14 feet on both areas.

The effect of latitude upon the survival of some introduced species is shown clearly by these results. Shortleaf and loblolly pines, both of southern origin, had an average survival of 2 and 6 percent, respectively. Virginia pine, also a southern species, had the next lowest survival, 38 percent, for the conifers tested. The remaining conifers are either northern species or are well adapted

to northern climatic conditions. These species had an average survival of 64 percent. The latitude effect is not as clear-cut for the hardwoods tested.

1949 Experiment

The experimental plots for this study were located near Muren, Pike County, and Midland, Greene County. On both areas the surface material resulting from mining Coal V was classified as shaly sandy loam, having a high proportion of thin-bed shale and soil-sized particles and a small proportion of massive sandstone and limestone. Approximately 15 percent of the Muren area was extremely acid (pH below 4.0) and about 5 percent was calcareous. The acidity of the rest of the area was fairly evenly distributed between these two extremes. Only about 3 percent of the Midland area had a pH below 4.0, and 30 percent was calcareous.

On each of the two areas three experimental blocks were established. One-half of each block was planted with several hardwoods in a row-wise mixture with black locust. The other half of each block was planted with the same species of hardwoods but without locust. Except for locust, all species were mixed within rows throughout the study. The following hardwoods were planted: ailanthus, ash, black locust, black walnut, chestnut oak, sweet gum, soft maple, yellow-poplar, sycamore, and cottonwood.

At the end of the first growing season, over-all survival was 84 percent. Disregarding mortality caused by acid-toxicity, survival was about the same on both areas and ranged from 92 percent for ash to 63 percent for sycamore. Black locust apparently had not yet affected the other hardwoods in the mixed plantings.

BLACK LOCUST AS A NURSE CROP

Black locust is a fast-growing tree which once was highly recommended and extensively planted in pure stands on coal-stripped lands. The almost universal failure of the species, caused by locust-borer injury, has made it necessary to reappraise its value in strip-land planting programs (7). Until very recently the site-improving qualities of locust have not been fully realized. Its high survival and rapid initial growth provide early cover and stabilization of the banks even under severe conditions of erosion and exposure and over a wide acidity range. In addition to these important considerations, locust increases fertility by adding nitrogen to the banks through nitrogen-fixation. The improved growth and survival of several hardwood species when planted under deteriorated locust stands has been demonstrated both on stripped lands (7) and on old fields (6). These results suggest that locust's poor showing as a commercial species may be compensated

for by its rapid site-improving characteristics. Its value as a nurse crop alone warrants considering it in future hardwood plantings.

Two types of locust-hardwood plantings are being tested on Indiana coal-stripped lands. These are: (1) simultaneous mixtures in which several species of hardwoods have been planted at the same time with varying percentages of locust, and (2) underplanting previously established black locust plantations with other hardwoods. The results of these experiments follow.

Locust-Hardwood Mixtures

The 1945 test of species adaptation established near Boonville and Riley included simultaneous mixtures of locust with sweet gum, soft maple, cottonwood, red oak, and yellow-poplar. These species, individually, were planted in row-wise mixtures with 25 percent and with 75 percent locust. The first three species also were planted without locust.

At the end of 4 years, survival and total height of cottonwood, sweet gum, and maple in the locust mixtures was no better than in the pure plantings. These studies are still too young to show the beneficial effects of locust when it is mixed simultaneously in plantings with other hardwoods. Also, any early effects that may have been present probably were obscured by acid-toxicity, flooding, and rabbit damage.

In the previously described 1949 experiment located near Muren and Midland, hardwood mixtures were planted with and without black locust. The plots with locust contained 50 percent locust in a row-wise mixture with 11 other hardwoods. At the end of the first year these plots had a survival of 90 percent, and the plots without locust had 83 percent. However, this initial difference in survival was not attributable to the effect of locust.

Underplanting with Other Hardwoods

In the spring of 1947 a 2-year-old locust plantation on the Boonville area was underplanted with six species of other hardwoods. At the time of underplanting the locust had close to 100 percent survival and averaged 6 feet tall. A 4-year-old locust plantation on the Riley area was underplanted with seven hardwood species in the spring of 1949. Locust survival here was also nearly 100 percent and the trees averaged 12 feet tall. There was some evidence that the locust borer had begun to attack this latter plantation.

Over-all survival and total heights of the underplanted hardwoods at the end of five seasons were 68 percent and 4.0 feet at Boonville. At Riley, after three seasons, survival averaged

75 percent and total height averaged 2.1 feet. These tests indicate that shade-intolerant species, such as cottonwood which failed completely, are not suitable for underplanting. Other, more tolerant species, such as ash, sweet gum, soft maple, yellow-poplar, and black walnut, survived and grew better under black locust than in plantings made on bare banks.

Survival and height data for a few selected hardwoods planted on bare mine banks and under locust plantations were summarized for comparative purposes. At 4 years, average survival and annual height growth for the bare-bank plantings were 20 percent and 0.7 feet (table 24). For underplantings of the same species, survival and height growth averaged 74 percent and 0.9 feet per year. These results indicate the beneficial effects of older locust plantings upon underplanted hardwoods.

Table 24.--Survival and average annual height growth at 4 years for selected hardwood species planted on open banks and under older black locust plantations on Indiana strip-mined land

Species	Open-bank plantings 1/		Underplantings	
	Survival	Average annual height growth	Survival	Average annual height growth
	Percent	Feet	Percent	Feet
Soft maple	26	0.9	75	1.0
Sweet gum	10	0.5	79	0.6
Yellow-poplar	23	0.7	67	1.0
Average	20	0.7	74	0.9

1/ Yellow-poplar planted in simultaneous 25-percent mixture with black locust; all other species planted in pure stands.

Early results of experiments on strip-mined lands in Indiana to test the effect of black locust on the growth of associated species are inconclusive. Studies must be continued for a number of years before positive evidence becomes available. These preliminary findings, augmented by results of similar experiments elsewhere in the Central States (6, 7, 17), do, however, show beneficial effects under certain specific conditions. The effects will vary not only with species and sites, but also with different proportions of locust and the time at which other species are interplanted or underplanted. All of these related factors are being studied in current investigations. Until they can be evaluated, recommendations for the use of black locust in mixed planting must necessarily be

general. As more information becomes available, more specific recommendations can be made with respect to planting mixtures as well as to possible cultural measures needed to maintain rapid growth.

SUMMARY

RESULTS OF INDIANA STUDIES

Among the geologic characteristics which influence the quality of Indiana coal-stripped lands for forest growth, two of the most important are the occurrence of glacial deposits and of highly sulphurous strata above the coal. Differences in the distribution, depth, and age of glacial till are used as a basis for dividing the coal-bearing area of the state into three regions: Wisconsin glaciated; Illinoian glaciated; and unglaciated. Potentially acid sulphurous materials commonly are present near coal formations, but they differ somewhat by coal seams in their composition and extensiveness in the overburden. The effects of glaciation and sulphur concentrations upon bank type are modified by variations in methods of stripping.

Information on the later growth and development of trees on strip-mined lands in the state was obtained by examining a naturally forested area and a number of early company plantings. The natural forest was found to be very poorly stocked and consisted chiefly of low-quality timber. Considering, also, observations made elsewhere, the early development of acceptable volunteer stands on stripped land appears limited to areas which are near seed sources of desirable tree species. In sharp contrast, many of the early plantings have become productive young forests, although mistakes often were made in methods of planting and in selection of species. Of three major plantation types encountered, the pine plantations have been most successful thus far. Pine-hardwood mixtures have been thinned excessively by competition among interplanted species with different growth rates and by the deterioration of black locust. Early plantings of pure hardwoods were limited to black walnut. This species has grown only about two-thirds as fast in the pure stands as in mixtures containing black locust.

Analyses were made to determine the effect of several major environmental factors on the success of older plantations. The results showed that certain conditions of acidity, topographic position, and texture significantly influenced height growth. On those areas where highly acid surface material occupied 10 percent or more of the area, the mean annual growth of pine plantations was reduced by about 0.3 feet. Similarly, growth rates were

slower on upper slopes than lower slopes, especially on the higher banks and those composed of coarser-textured materials. Erosion and sedimentation, common causes of injury and mortality in young plantings, were not important factors affecting their later growth.

Studies of the older plantations yielded some preliminary information on management aspects. In addition to protecting the trees from injurious agencies, thinning and pruning are often advisable when the trees are 18 to 20 years old to maintain or improve the quality and rate of growth. Cutting and harvesting techniques which will promote natural regeneration of the better planted or volunteer species must also be developed. In some cases where seed sources of desirable species are not available, as in most pure black locust plantations, additional planting may be necessary.

Experimental plantings have been made on several strip-mined areas in Indiana to test the suitability of various species and to evaluate the effect of black locust as a nurse crop. Although these stuides are still too young to provide conclusive evidence, some information has been acquired on early survival and growth.

FOREST PLANTING RECOMMENDATIONS

Preliminary planting guides are presented here to help those engaged in the forestation of coal-stripped lands in Indiana. These tentative recommendations are based chiefly upon information obtained from the reconnaissance of stripped lands, from the surveys of older plantations, and from experimental plantings in Indiana, Illinois, and Ohio. Species other than those recommended should not be planted extensively until their suitability to climatic and local mine-bank conditions has been determined.

Because of the influence of glaciation upon bank characteristics, individual planting guides have been prepared for strip-mined lands in the Wisconsin glaciated, the Illinoian glaciated, and the unglaciated regions of Indiana. The species recommended for planting are listed according to the predominant bank types occurring within each of these regions. Mixed plantings are recommended to minimize the loss caused by failure of any one species, and to increase the likelihood of obtaining suitable seed sources for future regeneration. The species used should be planted in groups or multiple rows to reduce competition. Additional supplementary recommendations are given for special conditions which may affect the selection of species or methods of planting.

Planting Guides

Wisconsin Glaciated Region

Major bank types	Species recommended: In multiple-row or group-wise mixtures	Species recommended: In mixtures containing 50 percent black locust
Acid loams and silty shales	Jack, red, and white pines, red cedar, cottonwood, sycamore, silver maple, red oak	White or green ash, sycamore, silver maple, red cedar, red oak, black walnut, yellow-poplar
Calcareous sands	Jack, red, and white pines	Hardwoods not recommended
Calcareous loams and silty shales	Sycamore, cottonwood, red cedar, red oak, silver maple, jack, red, and white pines	Black walnut, yellow-poplar, white or green ash, red oak, sycamore, silver maple, red cedar

Illinoian Glaciated Region

Major bank types	Species recommended[1]: In multiple-row or group-wise mixtures	Species recommended[1]: In mixtures containing 50 percent black locust
Acid or calcareous sands	Jack, red, white, Virginia, and pitch pines	Hardwoods not recommended
Acid loams and silty shales	Jack, red, and white pines, (red cedar), cottonwood, sycamore, silver maple, (chestnut oak), red oak, sweet gum, Virginia and pitch pines	White or green ash, sycamore, silver maple, (chestnut oak), (red cedar), red oak, sweet gum, black walnut, yellow-poplar
Calcareous loams and silty shales	Sycamore, cottonwood, (red cedar), red oak, (chestnut oak), silver maple, sweet gum, jack, red, and white pines	Yellow-poplar, black walnut, white or green ash, red oak, sycamore, (chestnut oak), silver maple, sweet gum, (red cedar)

1/ Recommendations of species in parentheses are based upon observations and experimental evidence in other states. Caution should be used in planting these species until further proof of their suitability is available.

Unglaciated Region

Major bank types	Species recommended[1/] In multiple-row or group-wise mixtures	Species recommended[1/] In mixtures containing 50 percent black locust
Acid sands	Shortleaf, jack, (loblolly), red, white, Virginia, and pitch pines	Hardwoods not recommended
Acid loams and silty shales	Shortleaf, jack, (loblolly), red, white, Virginia, and pitch pines, cottonwood, sycamore, (red cedar), silver maple, (chestnut oak), red oak, sweet gum	White or green ash, sycamore, silver maple, (chestnut oak), (red cedar), red oak, sweet gum, black walnut, yellow-poplar
Calcareous loams and silty shales	Sycamore, cottonwood, (red cedar), silver maple, red oak, (chestnut oak), sweet gum, shortleaf, jack, (loblolly), red, and white pines	Yellow-poplar, black walnut, white or green ash, sweet gum, sycamore, red oak, (chestnut oak), silver maple, (red cedar)

1/ Recommendations of species in parentheses are based upon observations and experimental evidence in other states. Caution should be used in planting these species until further proof of their suitability is available.

Supplementary Recommendations

Banks Containing Less Than 40 Percent Soil-sized Material

The pines, cottonwood, and sycamore generally are well adapted to dry site conditions found on very rocky stripped lands. Allowing such material to weather for 3 or 4 years before planting often will increase the "soil" content sufficiently so that hardwood mixtures, including black locust, can be successfully introduced.

Highly Erosive Banks

Erosion is most apt to be a limiting factor to plantation establishment on high, steep banks composed largely of sand or glacial till. Black locust, spaced at relatively close intervals, should either be planted pure and underplanted later with other

species or be planted in mixtures containing small proportions of ash, silver maple, and sycamore. To minimize early mortality from washing, care should be taken that the trees are planted on the ridges between gulleys.

Banks Having a Dense Cover of Sweet Clover

Competition from dense sweet clover causes high initial mortality among many tree species. Green and white ash and eastern red cedar appear best suited for planting under such conditions.

Underplanting Decadent Black Locust

Non-productive black locust plantations which have a relatively light ground cover often can be successfully underplanted with desirable species. Some very good results have been obtained with yellow-poplar, black walnut, silver maple, sweet gum, and eastern red cedar. Cottonwood, sycamore, and pine species should not be planted under a locust cover.

Christmas Tree Plantings

Red, Scotch, jack, and Virginia pines and eastern red cedar are species which can be grown on Indiana stripped lands for Christmas trees or greens. Closer spacings than are normally used should be followed in plantings made for these purposes.

LITERATURE CITED

(1) Arnott, Donovan, Jr.
1950. Initial survival of planted hardwoods on strip-mine spoil banks of Indiana. (Unpublished master's thesis. Copy on file, Dept. of Forestry, Purdue Univ.)

(2) Ashley, G. H.
1899. The coal deposits of Indiana. Indiana Dept. Geol. and Nat. Resources, 23d Ann. Rpt.

(3) Brooks, Maurice G.
1951. Effect of black walnut trees and their products on other vegetation. W. Va. Univ. Agr. Expt. Sta., Bul. 347, 31 pp.

(4) Bureau of the Census
1947. County data book. U. S. Dept. Commerce.

(5) Chapman, A. G.
1944. Forest planting on strip-mined coal lands with special reference to Ohio. Central States Forest Expt. Sta., Tech. Paper 104, 25 pp.

(6) -------------, and Lane, R. D.
1951. Effects of some cover types on interplanted forest tree species. Central States Forest Expt. Sta., Tech. Paper 125, 15 pp.

(7) Deitschman, G. H.
1950. Comparative survival and growth of trees planted under three types of overhead cover on strip-mined land in southern Illinois. Central States Forest Expt. Sta., Sta. Note 63, 2 pp.

(8) ----------------, and Lane, R. D.
1951. How strip-mined lands grow trees profitably. Coal Age, December.

(9) DenUyl, D.
1948. Forest plantations, their establishment, growth and management. Purdue Univ. Agr. Expt. Sta., Sta. Cir. 331

(10) Gaiser, R. N., and Merz, R. W.
The growth of planted red and white pines in relation to the soil and topography of old fields in the unglaciated region of Ohio and Central Indiana. Central States Forest Expt. Sta. (Unpublished manuscript.)

(11) Holsoe, Torkel
1950. Profitable tree forms of yellow poplar. W. Va. Univ. Agr. Expt. Sta., Bul. 341, 5 pp.

(12) Kellogg, Leonard F.
1939. Site index curves for plantation black walnut, Central States Region. Central States Forest Expt. Sta., Sta. Note 35.

(13) Lesquereux, Leo
1862. Report on the distribution of the geological strata in the Coal Measures of Indiana, in Owen, R., Report of a geological reconnaissance of Indiana.

(14) Limstrom, G. A.
1948. Extent, character, and forestation possibilities of land stripped for coal in the central states. Central States Forest Expt. Sta., Tech. Paper 109, 79 pp.

(15) ---------------
Moisture conditions and plantation success on graded and ungraded strip-mined lands. Central States Forest Expt. Sta. (Unpublished manuscript.)

(16) ---------------, and Deitschman, G. H.
1951. Reclaiming Illinois strip coal lands by forest planting. Univ. of Ill. Agr. Expt. Sta., Bul. 547, 50 pp.

(17) ---------------, and Merz, R. W.
1949. The rehabilitation of lands stripped for coal in Ohio. Central States Forest Expt. Sta., Tech. Paper 113, 41 pp.

(18) Logan, W. N.
1927. Analyses of Indiana coals. Bureau of Mines, Tech. Paper 417, 50 pp.

(19) Lorenz, Ralph W., and Spaeth, J. Nelson
1947. The growth of conifers on prairie soil. Jour. For. 45:253-256.

(20) Lutz, Harold J., and Chandler, Robert F.
1947. Forest soils. 370 pp. New York and London.

(21) Merz, R. W.
1949. Character and extent of land stripped for coal in Kentucky. Ky. Agr. Expt. Sta., Cir. 66, 27 pp.

(22) -----------, and Finn, R. F.
1951. Differences in infiltration rates on graded and ungraded strip-mined lands. Central States Forest Expt. Sta., Sta. Note 65, 2 pp.

(23) Merz, R. W., and Plass, W. T.
1952. Natural forestation on a strip-mined area in Ohio. Central States Forest Expt. Sta., Sta. Note 68, 2 pp.

(24) Moore, H. R., and Headington, R. C.
1940. Agriculture and land use as affected by strip mining of coal in eastern Ohio. Ohio Agr. Expt. Sta., Bul. 135, 40 pp.

(25) Neckers, J. W., and Walker, Charles R.
A field test for active sulfides in soil. (Accepted for publication in Soil Science.)

(26) Rogers, Nelson F.
1951. Strip-mined lands of the Western Interior Coal Province. Mo. Agr. Expt. Sta., Res. Bul. 475, 55 pp.

(27) Rudolf, Paul O.
1950. Forest plantations in the Lake States. U. S. Dept. Agr., Tech. Bul. 1010, pp. 120-126.

(28) Sawyer, L. E.
1949. The use of surface mined land. Jour. Soil and Water Conserv. 4:161-166.

(29) -------------
1951. End use of forest products [from strip-mine lands]. (Paper read before American Mining Congress.)

(30) Schnur, G. Luther
1937. Yield, stand, and volume tables for even-aged upland oak forests. U. S. Dept. Agr., Tech. Bul. 560, 88 pp.

(31) Stiver, E. N.
1949. Revegetation of strip-coal spoil banks of Indiana. (Unpublished doctor's thesis. Copy on file, Dept. of Forestry, Purdue Univ.)

(32) Thornbury, W. D.
1937. Glacial geology of southern and south-central Indiana. Ind. Div. Geol. Pub., 146 pp.

(33) Weller, J. M., and Wanless, H. R.
1939. Correlation of minable coals of Illinois, Indiana, and western Kentucky. Ill. State Geol. Surv. Cir. 48, 18 pp.

(34) Wier, Charles E.
1950. Geology and coal deposits of the Jasonville Quadrangle, Clay, Greene, and Sullivan Counties, Indiana. U. S. Bureau of Mines, Coal Investig. Map C-1.

(35) Wilcox, R. F.
1929. Stripped-over coal plantings in Indiana. (Unpublished report. Copy on file, Dept. of Forestry, Purdue Univ.)

APPENDIX

COMMON AND SCIENTIFIC NAMES OF TREE SPECIES MENTIONED IN THE TEXT

Ailanthus	*Ailanthus altissima* Mill.
Ash, black	*Fraxinus nigra* Marsh.
Ash, green	*Fraxinus pennsylvanica* var. *lanceolata* Borkh.
Ash, white	*Fraxinus americana* L.
Birch, river	*Betula nigra* L.
Boxelder	*Acer negundo* L.
Cherry, black	*Prunus serotina* Ehrh.
Cottonwood	*Populus deltoides* Marsh.
Elm, American	*Ulmus americana* L.
Elm, slippery	*Ulmus rubra* Muhl.
Gum, black	*Nyssa sylvatica* Marsh.
Gum, sweet	*Liquidambar styraciflua* L.
Hackberry	*Celtis occidentalis* L.
Hickory	*Carya* spp. Nutt.
Locust, black	*Robinia Pseudo-Acacia* L.
Maple, red	*Acer rubrum* L.
Maple, silver	*Acer saccharinum* L.
Mulberry, red	*Morus rubra* L.
Oak, black	*Quercus velutina* Lam.
Oak, chestnut	*Quercus montana* Willd.
Oak, chinquapin	*Quercus muehlenbergii* Engelm.
Oak, northern red	*Quercus rubra* var. *borealis* Michx.
Oak, pin	*Quercus palustris* Muenchh.
Oak, shingle	*Quercus imbricaria* Michx.
Oak, swamp white	*Quercus bicolor* Willd.
Oak, white	*Quercus alba* L.
Osage orange	*Maclura pomifera* (Raf.) Schneid.
Persimmon	*Diospyros virginiana* L.
Pine, Austrian	*Pinus nigra* Arnold
Pine, eastern white	*Pinus strobus* L.
Pine, jack	*Pinus banksiana* Lamb.
Pine, loblolly	*Pinus taeda* L.
Pine, pitch	*Pinus rigida* Mill.
Pine, red	*Pinus resinosa* Ait.
Pine, Scotch	*Pinus sylvestris* L.
Pine, shortleaf	*Pinus echniata* Mill.
Pine, Virginia	*Pinus virginiana* Mill.
Redbud	*Cercis canadensis* L.
Red cedar, eastern	*Juniperus virginiana* L.
Sassafras	*Sassafras albidum* (Nutt.) Nees.
Spruce, white	*Picea glauca* (Moench.) Voss
Sycamore	*Platanus occidentalis* L.
Walnut, black	*Juglans nigra* L.
White cedar, northern	*Thuja occidentalis* L.
Willow, black	*Salix nigra* Marsh.
Yellow-poplar	*Liriodendron tulipifera* L.

Table 25.--Area of strip-mined land in Indiana by acidity and texture classes, 1947

Acidity class	Sands		Loams and silty shales		Clay		Total	
	Acres	Percent	Acres	Percent	Acres	Percent	Acres	Percent
Toxic. More than 75% of area with pH less than 4.0	458	1.1	241	0.6	0	0.0	699	1.7
Marginal. 50-75% toxic. Less than 51% with pH 4.0-6.9, and less than 51% with pH 7.0+	247	0.6	947	2.2	0	.0	1,194	2.8
Acid. More than 50% with pH of 4.0-6.9	905	2.2	30,425	72.6	0	.0	31,330	74.8
Calcareous. More than 50% with pH of 7.0 or higher	774	1.8	7,191	17.2	0	.0	7,965	19.0
Mixed. Approximately the same proportion of toxic, acid and calcareous areas	27	0.06	682	1.6	12	.02	721	1.7
Total	2,411	5.8	39,486	94.2	12	.02	41,909	100.0

Table 26.--Area of strip-mined land in Indiana by county, acidity class, and soil texture,[1] 1947

County	Toxic		Marginal		Acid		Calcareous		Mixed			Total
	Sands	Loams	Sands	Loams	Sands	Loams	Sands	Loams	Sands	Loams	Clay	
	Acres											
Clay	22	26	0	0	52	5,952	0	1,257	0	577	12	7,898
Daviess	0	0	0	0	0	27	0	0	0	0	0	27
Dubois	0	12	0	0	0	0	0	0	0	0	0	12
Fountain	0	46	0	0	0	76	0	83	0	0	0	205
Gibson	0	0	0	0	0	129	0	0	0	0	0	129
Greene	0	98	0	0	0	3,959	0	1,357	0	0	0	5,414
Knox	0	0	0	0	0	468	0	107	0	0	0	575
Owen	0	0	0	0	9	1,024	0	24	0	0	0	1,057
Parke	0	0	0	0	0	18	11	133	0	0	0	162
Pike	436	0	83	764	480	8,710	0	0	0	0	0	10,473
Spencer	0	0	0	0	0	772	0	0	0	0	0	772
Sullivan	0	3	0	26	0	3,831	0	411	0	0	0	4,271
Vermillion	0	0	0	0	0	132	763	304	27	37	0	1,263
Vigo	0	56	27	141	35	1,439	0	1,978	0	0	0	3,676
Warrick	0	0	137	16	329	3,888	0	1,537	0	68	0	5,975
Total	458	241	247	947	905	30,425	774	7,191	27	682	12	41,909

1/ Silty shales are included under "loams."

Table 27.--Area of strip-mined land in Indiana by county and character of vegetation, 1947

County	Barren: No cover	Barren: Poor stocking - Trees: Planted	Barren: Poor stocking - Trees: Volunteer	Barren: Poor stocking: Herbs 1/	Barren: Poor stocking: Herbs and trees 2/	Herbs: Fair to good stocking: Weeds and grasses	Herbs: Fair to good stocking: Legumes	Herbs: Fair to good stocking: Mixed 3/	Herbs: Fair to good stocking: Herbs and trees 4/	Forested: Good stocking: Planted	Forested: Good stocking: Volunteer	Forested: Good stocking: Planted & volunteer (mixed)	Forested: Fair stocking: Planted	Forested: Fair stocking: Volunteer	Forested: Fair stocking: Planted & volunteer (mixed)	Total area stripped	Area used as pasture
	Acres																
Clay	918	95	73	436	1,642	49	144	373	19	1,644	508	317	362	1,202	116	7,898	101
Daviess	24	0	0	0	0	0	0	0	0	3	0	0	0	0	0	27	0
Dubois	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	12	0
Fountain	96	0	0	0	21	41	0	0	0	44	0	0	0	3	0	205	32
Gibson	0	0	0	0	0	0	0	0	0	129	0	0	0	0	0	129	0
Greene	213	0	0	181	143	37	146	852	54	1,838	332	0	518	1,077	23	5,414	326
Knox	0	81	0	195	0	0	0	0	0	56	0	0	108	28	107	575	0
Owen	115	0	54	0	100	6	83	93	0	117	0	83	0	377	29	1,057	39
Parks	19	0	5	11	0	5	0	0	0	47	23	0	9	43	0	162	11
Pike	2,298	583	55	833	19	34	0	182	0	4,360	518	40	1,298	115	138	10,473	5
Spencer	329	6	0	72	0	0	0	0	69	294	0	0	2	0	0	772	0
Sullivan	426	6	0	33	0	181	363	229	18	1,416	175	265	692	347	120	4,271	227
Vermillion	36	0	0	49	0	54	634	11	27	152	0	87	67	146	0	1,263	0
Vigo	602	122	27	0	250	48	16	62	142	440	46	581	823	517	0	3,676	0
Warrick	706	0	148	189	26	100	0	716	91	3,305	473	0	136	62	23	5,975	72
Total	5,782	893	374	1,999	2,201	555	1,386	2,518	420	13,845	2,075	1,373	4,015	3,917	556	41,909	813
Group totals	11,249					4,879				17,293			8,488				
										25,781							

1/ Includes weeds, grasses, shrubs, and legumes.
2/ Includes poor stocking of planted and volunteer trees with poor stocking of weeds, grasses, and legumes.
3/ Mixture of weeds, grasses, and legumes.
4/ Fair to good stocking of weeds, grasses, and legumes; poor stocking of planted trees.

Table 28.--Area of strip-mined land in Indiana by county and coal seam, 1947

County	Block	Minshall	No. III	No. IV	No. V	No. VI	No. VII	Total
				-Acres-				
Clay	0	5,942	1,718	0	238	0	0	7,898
Daviess	0	0	0	27	0	0	0	27
Dubois	0	0	0	12	0	0	0	12
Fountain	205	0	0	0	0	0	0	205
Gibson	0	0	0	0	129	0	0	129
Greene	0	138	130	2,524	1,746	544	332	5,414
Knox	0	0	0	0	0	575	0	575
Owen	0	1,057	0	0	0	0	0	1,057
Parke	11	151	0	0	0	0	0	162
Pike	0	0	0	0	10,473	0	0	10,473
Spencer	0	0	0	0	772	0	0	772
Sullivan	0	0	0	0	899	2,553	819	4,271
Vermillion	0	0	0	0	189	1,074	0	1,263
Vigo	0	0	328	848	2,313	187	0	3,676
Warrick	0	0	0	0	5,175	800	0	5,975
Total	216	7,288	2,176	3,411	21,934	5,733	1,151	41,909

The regression formulas and correlation coefficients showing the relationship between stand density and age at which diameter growth was retarded in the older pine plantations (pp. 23, 24, fig. 12) are as follows:

Jack pine - $\hat{y} = 11.9 - 0.3416x$; $r = -0.427$**
Red pine - $\hat{y} = 12.2 - 0.1997x$; $r = -0.231$
White pine - $\hat{y} = 15.4 - 0.4134x$; $r = -0.520$**
Scotch pine - $\hat{y} = 10.2 - 0.1043x$; $r = -0.283$**
Austrian pine - $\hat{y} = 10.6 - 0.1014x$; $r = -0.144$

**Highly significant correlation; others are not significant.

TERRITORY SERVED BY THE

CENTRAL STATES FOREST EXPERIMENT STATION

FOREST SERVICE

U. S. DEPARTMENT OF AGRICULTURE